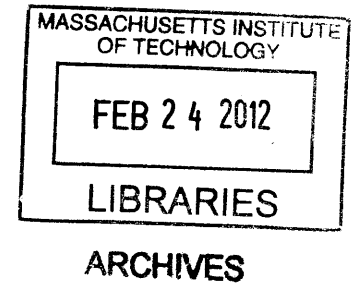


EXPANDABLE HOUSE

For Disaster Relief and Flexible Dwelling

by
Mimi Ho Chu
B.F.A. Environmental Design, 2008
Ewha Woman's University



Submitted to the Department of Architecture in Partial Fulfillment of the Requirements for the Degree of
MASTER OF ARCHITECTURE
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

February 2012

© 2012 Mimi Ho Chu. All rights reserved.

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic
copies of this thesis document in whole or in part in any medium now known or hereafter created.

Signature of Author.....

Department of Architecture
January 19, 2012

Certified by.....

Yung Ho Chang
Professor of Architecture

Accepted by.....

Takehiko Nagakura
Associate Professor of Design and Computation
Chair of the Department Committee on Graduate Students

THESIS COMMITTEE

Thesis Supervisor

Yung Ho Chang

Professor of Architecture

Department of Architecture

Reader

Nick Gelpi

Lecturer

Department of Architecture

EXPANDABLE HOUSE

For Disaster Relief and Flexible Dwelling

by
Mimi Ho Chu

Submitted to the Department of Architecture on January 19th, 2012
in Partial Fulfillment of the Requirements for the Degree of
MASTER OF ARCHITECTURE

ABSTRACT

In March 2011, a devastating earthquake and tsunami struck northern Japan. In addition to the lives lost, thousands of people were dislocated, resulting in an urgent need for housing. My approach is to design the Expandable House, which is lightweight, easy to transport, quickly assembled, and sustainable. In a typical disaster relief timeline, three types of housing are provided. The first response to post-disaster housing is the assembly of lightweight emergency tents in relief camps, but these tents lack privacy, stability, and living conditions like insulation, heating, and ventilation. Therefore these tents are often replaced by temporary shelters such as trailers, shacks, and prefabricated houses, while the permanent housing is being constructed. However, these temporary structures double the cost of the overall solution because of the building materials and labor involved in building and deconstructing the temporary structures and rebuilding a new house.

This thesis proposes to merge these different stages of housing into one through designing an expandable architecture. The house could be easily transported and deployed for disaster relief, and could be folded and transported again to be reused for a permanent house afterwards. Compared with other existing prefab housing systems, the scissor mechanism allows occupancy of the house during the expansion and contraction processes because the structure remains intact while it is being transformed. The ability to fold a house allows for flexible use of the site and space in a variety of urban settings. The flexibility provides opportunities to operate the house in different climate conditions while providing multiple options for day lighting, insulation, and ventilation. By using an aluminum scissor structure and fabric-laminated foam insulation, the project explores new materials and fabrication technology for a flexible architecture.

Thesis supervisor: Yung Ho Chang

Title: Professor of Architecture

ACKNOWLEDGMENTS

I would like to express my gratitude to the following people:

To all my professors, classmates, and friends for your support and valuable advice during the years at MIT.

To Professor Yung Ho Chang and Nick Gelpi for their critique and encouragement.

And hearty thanks to Wonjung Kim, Jungpyo Lee, and Yuna Kim for your caring, friendship, and help with model-building and drawings at the time when I needed you most.

Thank you.

Mimi Ho Chu, January 19, 2012

Table of Contents

0 Introduction	7
Disaster Response and Shelter Strategy	
Housing Typology in Post-disaster Timeline	
Proposal	
Increased Lifecycle of Transportable House	
1 Mobility in Architecture	13
History of mobile architecture	
Case Study	
2 Design	23
Foldable Structure	
Study1. Expandable House through Hinged Cladding	
Study2. Expandable House through Origami-folded Cladding	
Construction Sequence	
Expansion Sequence	
3 Drawings & Fabrication	39
Material	
Exploded Axonometric	
Plan & Detail	
Elevation	
Section & Detail	
1:2 Mockup Detail	
4 Program & Transformation	61
Sectional Perspective: Daily Transformation	
Longitudinal Section: Daily Transformation	
Daylighting Study	
Climate Control and Energy Saving	
Axonometric	
Rendering	
Bibliography	77

A large, light gray, semi-transparent number '0' is positioned on the right side of the slide, serving as a background for the title.

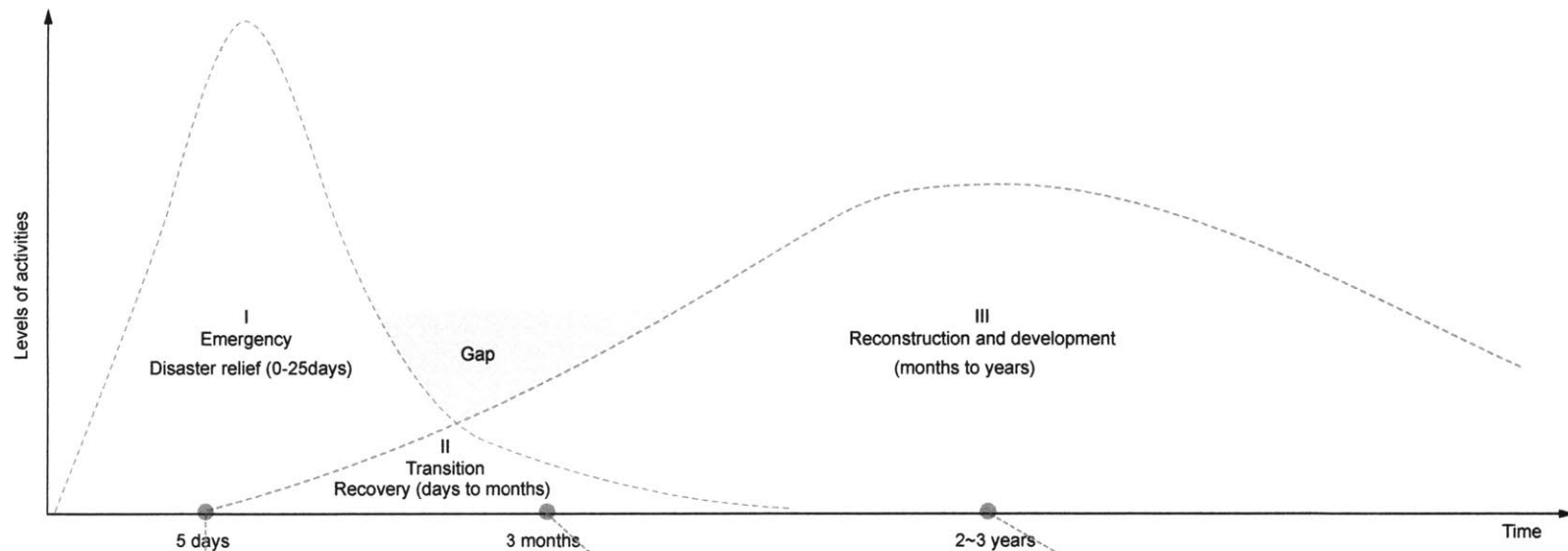
Introduction

Disaster Response and Shelter Strategy

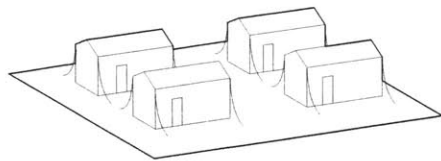
In March 2011, when the earthquake and tsunami struck northern Japan, thousands of people were dislocated, resulting in an urgent need for housing. Besides the urgent need, there was also a long-term demand for a comprehensive redevelopment, which may take several years. In order to meet both long-term and short-term needs, activities following a disaster take three major phases. Immediate *disaster response* takes place after the disaster for 0-25 days rescuing lives, providing emergency shelter, food, and providing medical aid. The second phase is *Disaster recovery*, which takes several days to several months, moving the population from emergency shelters to transitional camps where they resume normal life, in which water, sanitation, nutrition, and public health needs are met as soon as possible. Transportation, utilities, and economic activities are restored. While the region is returning to normality, *reconstruction* takes several months to several years rebuilding the infrastructure, roads, and bridges are repaired, or rebuilt.

During these three phases, three types of housing are provided. The first response to post-disaster housing is the assembly of lightweight emergency tents in relief camps, but these tents lack privacy, stability, and living conditions like insulation, heating, and ventilation. Therefore these tents are often replaced by temporary shelters such as trailers, shacks, and prefabricated houses, while the permanent housing is being constructed. However, these temporary structures double the cost of the overall solution because of the building materials and labor involved in building and deconstructing the temporary structures and rebuilding a new house.

Housing Typology in Post-disaster Timeline



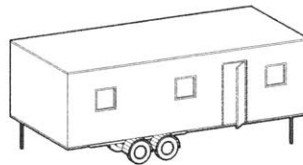
Emergency Tents in Relief Camps



Pro:
Lightweight, immediate transport, distribution and construction

Cons:
Lack privacy, stability, and living conditions such as electricity, heating, insulation, and ventilation

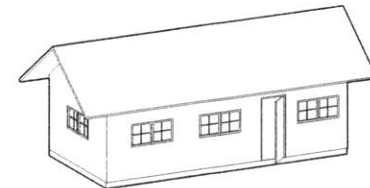
Transitional Shelter



Pro:
Provides more durable private shelter to resume normal life while permanent housing is being constructed

Cons:
Double the cost of the overall solution because of the building materials and labor involved in building and deconstructing the temporary structures and rebuilding a new house.

Permanent House

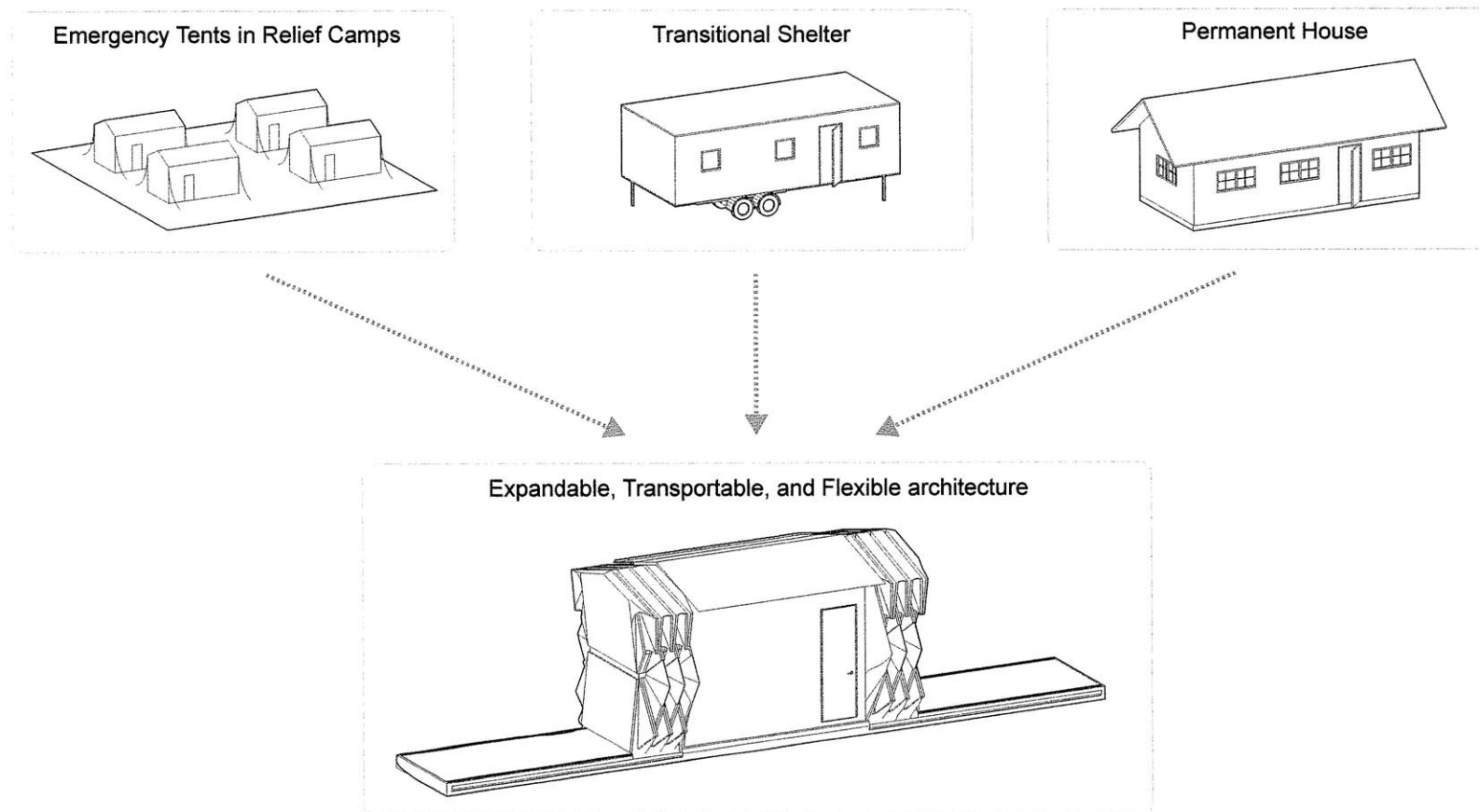


Pro:
Structurally durable
Provides better living condition for day lighting, heating, insulation, and ventilation

Cons:
Takes a couple of years to build a house.
Not flexible for lot size and site condition

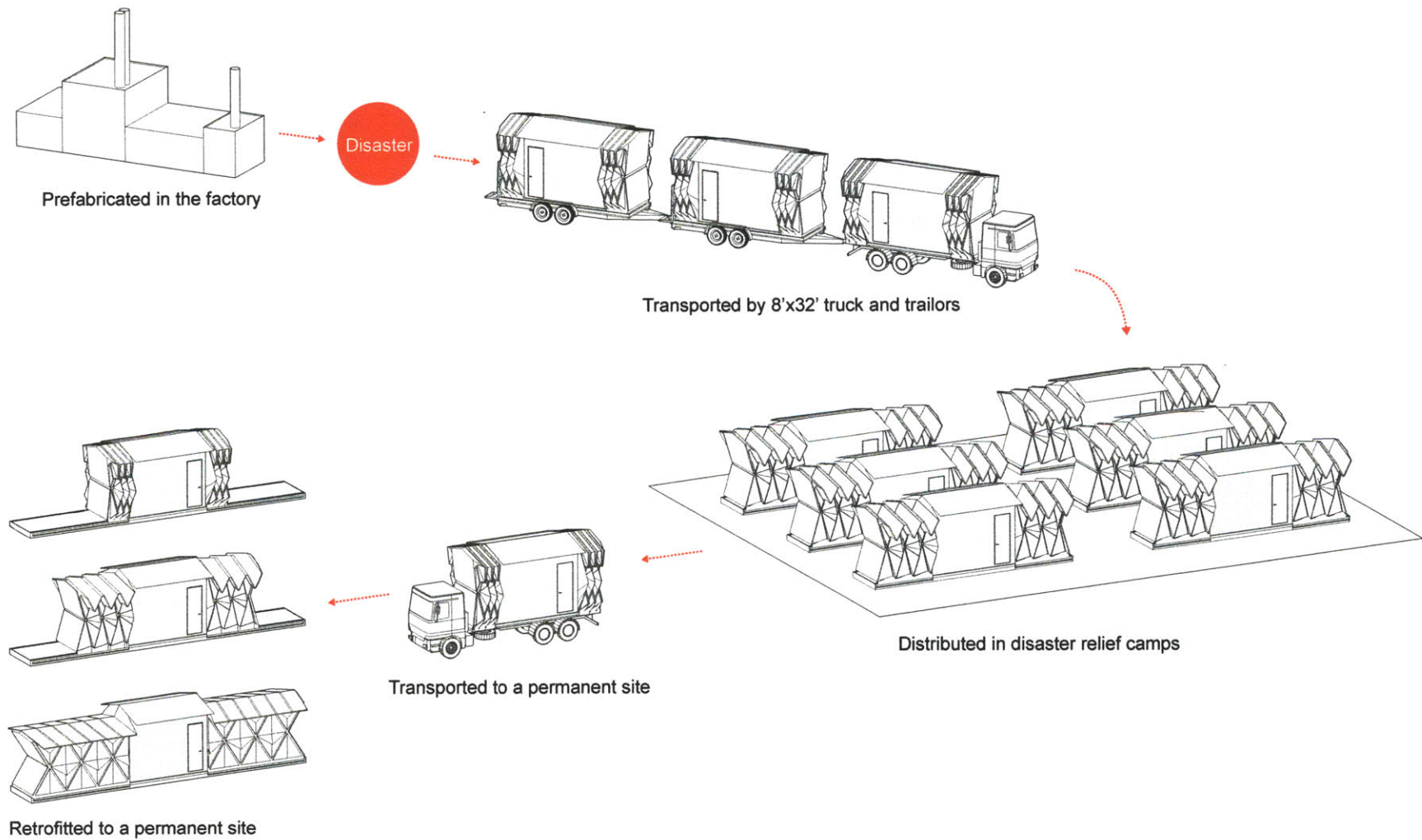
Proposal

This thesis proposes to merge these different stages of housing into one through designing an expandable architecture. The house could be easily transported and deployed for disaster relief, and could be folded and transported again to be reused for other purposes afterwards, therefore increasing the economic and social sustainability of the overall housing solution for disaster relief.



Increased Lifecycle of Transportable House

Collapsible architecture will increase the lifecycle of a shelter by being able to be resold, recycled, re-located, and reused after first being used for disaster relief.



Mobility in Architecture

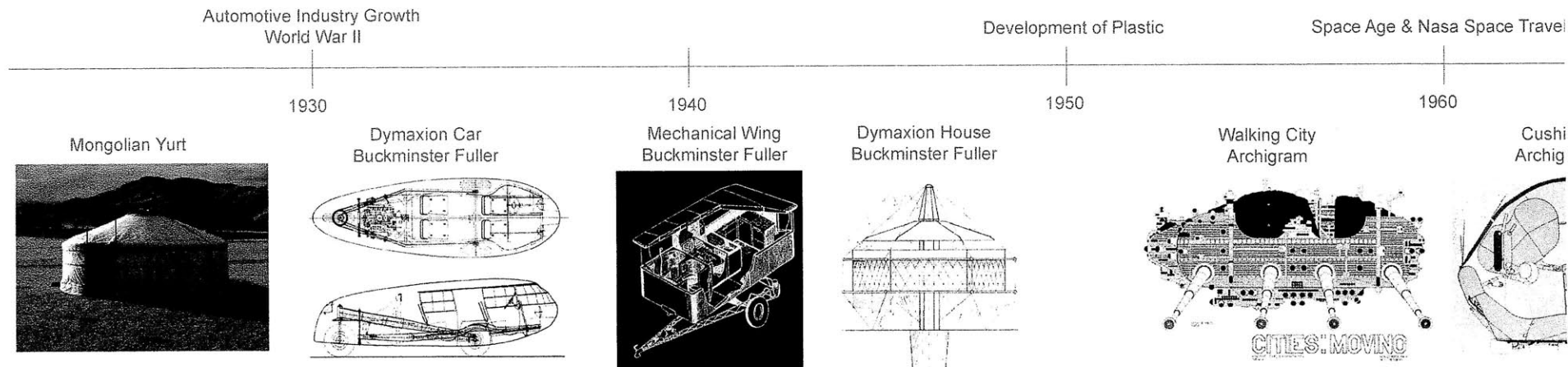
History of Mobile Architecture

1) Traditional portable architecture - Mongolian Yurt

There have been several forms of traditional portable architecture built by prehistoric nomads such as the tipi in North America, the tent structures in North Africa, and the yurt in Asia. The yurt is a traditional building that evolved over centuries and still provides ideas for design strategy for practical economic houses today. Yurts have a structure that is easily transportable and become solid once they are set up. The wall is made from strips that have a scissor joint, forming diagonal truss bracing around the circular perimeter of the house and tightened through a tension band. Felt is used to make a warm and weatherproof covering for the yurt.

Transportable and collapsible houses were developed in relationship with technological advances of material and manufacturing that occurred in the military, automobile, space craft, and leisure industries.

Wartime construction practices contributed to the industrialization of housing and the use of deployable “pre-fab” systems. The principles for military facilities were adaptability to site conditions, flexibility in layout and form, ease of transport and deployment, and economic manufacturing. Architects such as Frank Lloyd Wright, Philip Johnson, Charles and Ray Eames, Jean Prouve, Walter Gropius, and Buckminster Fuller focused on “pre-fab” housing with the idea to utilize industrial technology and factories in building construction, to mass-produce housing at an affordable cost. They believed that factory-built houses



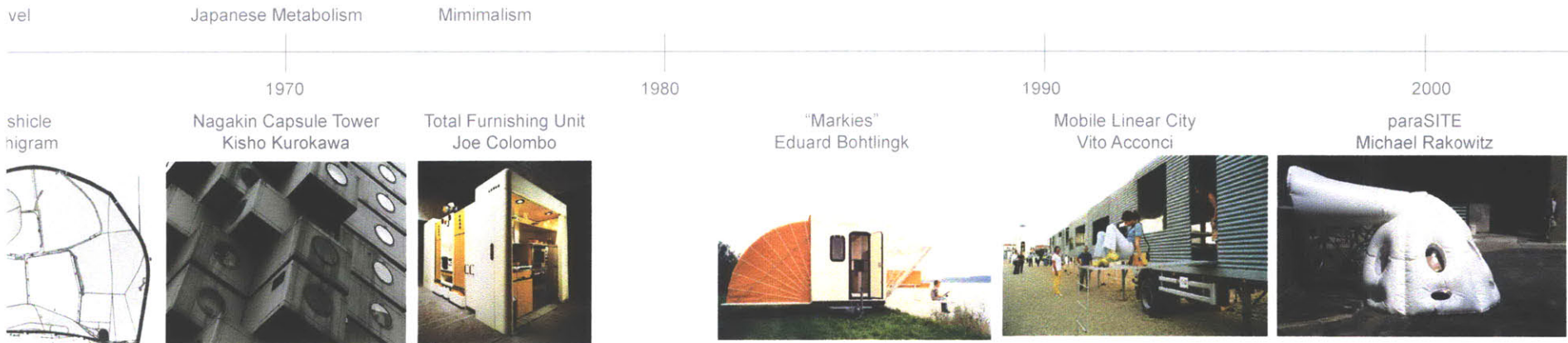
and modular building technology had the potential to offer society economic and aesthetic benefits. Standardization of construction and experimentation to increase speed, economy, and flexibility were encouraged.

The Surging automobile industry after the World WarII and vehicles for leisure influenced the interest in mobile architecture. Trailer homes and caravans are movable dwellings which were initially built for rich travelers. Buckminster Fuller's Mechanical Wing was one of the camper-trailers that contained washing, cooking and heating services.

Buckminster Fuller was interested in the efficiency of industrial production of housing and efficient transportation of buildings through lightweight and demountable systems. The Dymaxion house and the Wichita house were the innovative prototypes that Fuller developed with the interest in prefabrication and

transportation. His Dymaxion house was intended to relieve the large deficit of houses in the US after the war. It was a prototype for mass production in order to provide high-quality dwellings at an affordable cost. However, his house was not conceived as a "building" at that time, because it didn't look like a typical house.

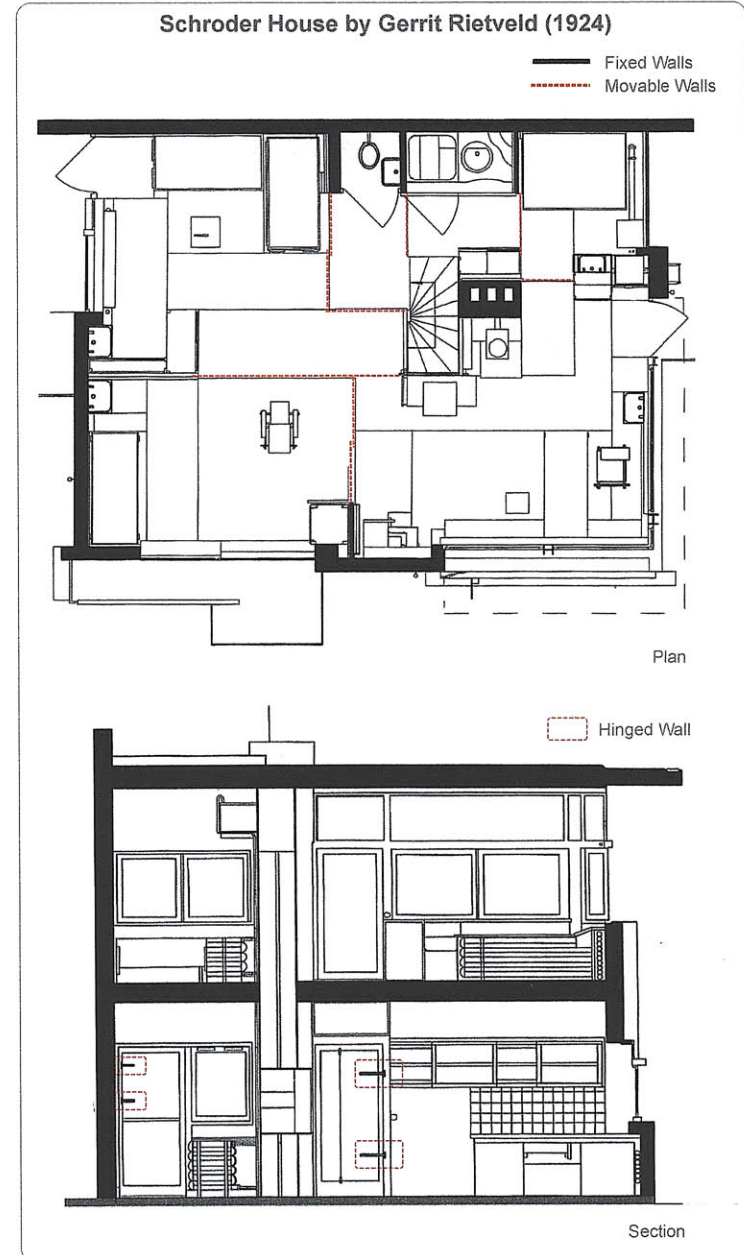
Frei Otto is best known for his lightweight cable-net structures. His experiences in the military industry influenced his future projects. He was initially trained as a sculptor, and became a glider pilot and then a fighter pilot during the Nazi period. After the Second World War, he worked on post-war rebuilding with the use of minimum and commonly available resources. His early work was influenced by tent-and sail-making techniques. Frei Otto was involved in the development of innovative structural forms such as pneumatic and lattice frames.



3) Flexible elements in open floor plans in modern architecture

After Mies van der Rohe advocated liberation of the floor, the modern movement was focused on the free plan of open interior space and its flexible use. Gerrit Rietveld used his early training as a cabinet-maker to create movable walls in the design of Schröder House. The movable walls allow the occupant to divide the one-room living space in a flexible pattern. The hinged sectional moveable screens of the first floor allow for the creation of one single continuous open space. As in the traditional Japanese house, the flexibility of Schröder House relies on the participation of the user, who can configure various possible plan layouts through moving internal partitions. During the day, the hinged screens are pushed towards the outer walls of the building and either kept in storage cupboards or gathered behind the walls. When the screens are closed, each room can be accessed separately from the hall: two rooms for sleeping and one room for living and dining.

Applying a similar system, contemporary architects such as Rem Koolhaas, Shigeru Ban, and Steven Holl designed aptable houses with flexible use of interior space allowing the occupants to change and create their own settings through movable elements. Steven Holl's apartment in Japan has movable walls that allow the occupants to adapt the space on a seasonal or daily basis for sleeping, eating, working, and leisure. In Shigeru Ban's house, sliding walls allow the interior to be subdivided into smaller rooms.

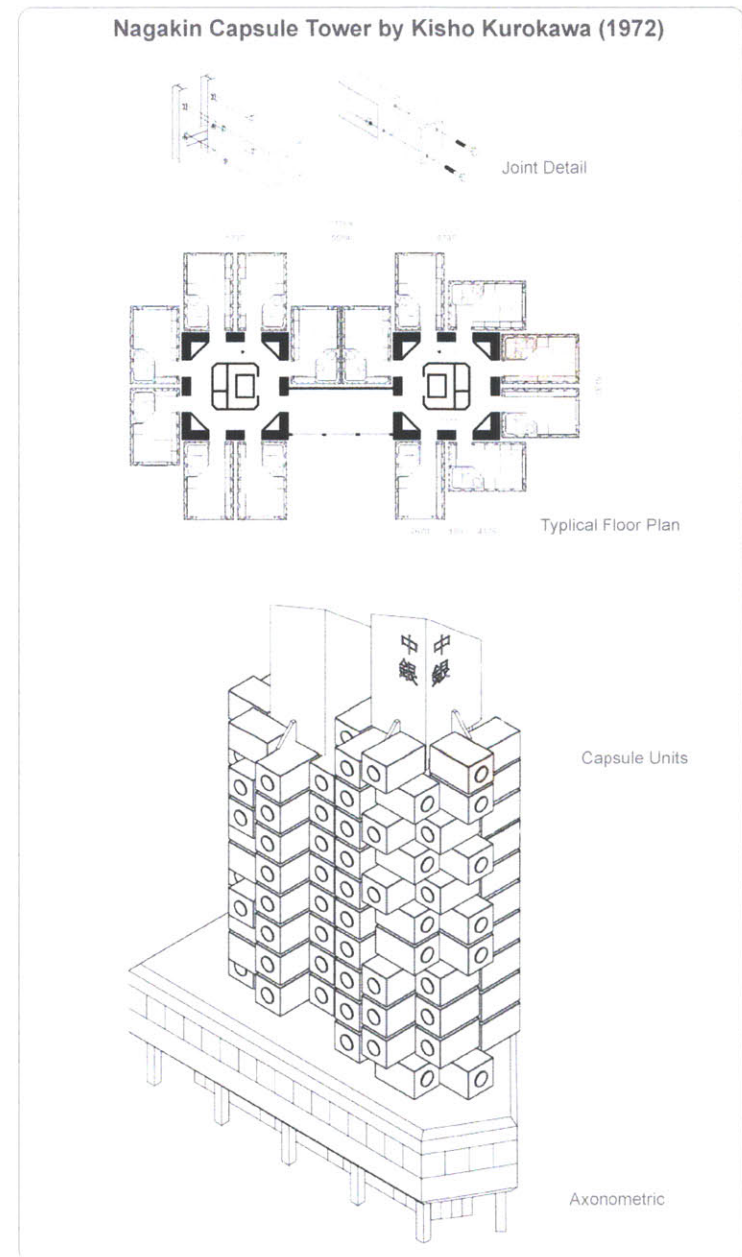


4) Contemporary forms of portable architecture

From the mid-1900s, young avant-garde groups experimented with new materials such as plastic to create provocative and unconventional designs. Kisho Kurokawa and Archigram proposed a prefabricated home that could be plugged into the urban superstructure. The emerging interest in the Space Age and NASA space travel program influenced architectural interest in survival capsules and mobile architecture as a wearable suit. Mike Webb's Cushicle(1966) was an inflatable living space that could be worn like a suit and converted to a personal vehicle. In the late 1960s, inflatable living space with pneumatic dwelling environment became the popular topic of experimentation among architects.

Case Study-Nagakin Capsule Tower by Kisho Kurokawa (1972)

The building is actually composed of two interconnected concrete towers, respectively eleven and thirteen floors, which house 140 prefabricated self-contained capsule units. Each capsule measures 2.3 m (7.5 ft) × 3.8 m (12 ft) × 2.1 m (6.9 ft) and functions as a small living or office space. Capsules can be connected and combined to create larger spaces. Each capsule is connected to one of the two main shafts by four high-tension bolts and is designed to be replaceable.



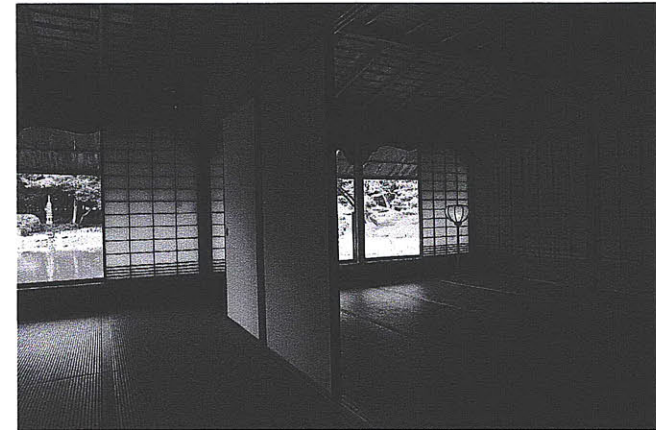
Case Study-Flexibility in Japanese House

Flexibility and adaptability in the Japanese house is achieved through the unit of tatami mat, sliding door(shoji), and movable panels(fusuma). The plan is organized as a series of interconnected spaces that can be joined or divided through sliding partition walls. The openness of the plan suggest that daily or periodic changes can be dealt with easily. Connections between rooms can be opened or closed through sliding screens, which make it possible to change the size and the function of a space in a few seconds: two individual rooms can be joined by simply opening up two large screens so that two small spaces become one large room that can be used for a specific festivity or family gathering.

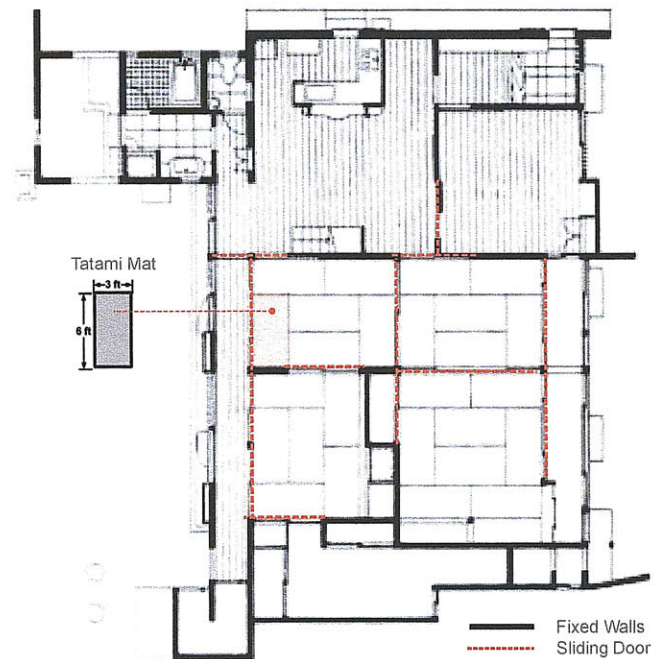
The actual flexibility and adaptability of the house is dependent upon the participation of the users; by pulling out futons from storage, a room that was used as a dining or sitting room can be transformed into a bedroom.

Flexibility is also enabled through a modular approach to design. The size of the rooms is based on the standard measure of tatami mats,(0.91m x 1.82m) with rooms made up of a set of these mats i.e. 6 or 8; these and other building components are thus interchangeable.

Traditional Japanese House



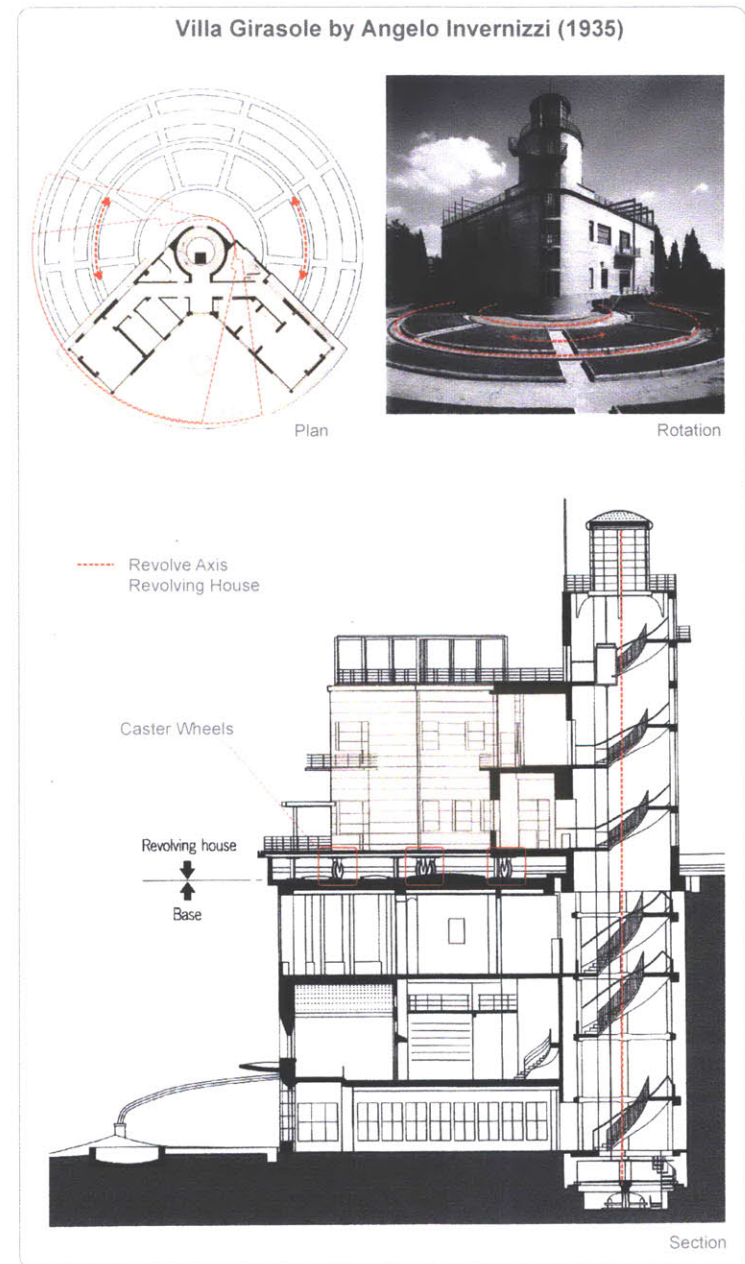
Fusuma (Movable Wall)



Japanese House Plan

Case Study-Villa Girasole by Angelo Invernizzi (1935)

In 1935, the Italian engineer Angelo Invernizzi created a kinetic architecture, which follows the motion of the sun. The villa is divided into two parts. The lower part is a three-story drum built into the hillside. A quadrant-shaped platform supports a two-story L-shaped house and the entire assemblage is mounted on 15 wheeled platform running on three circular rails.

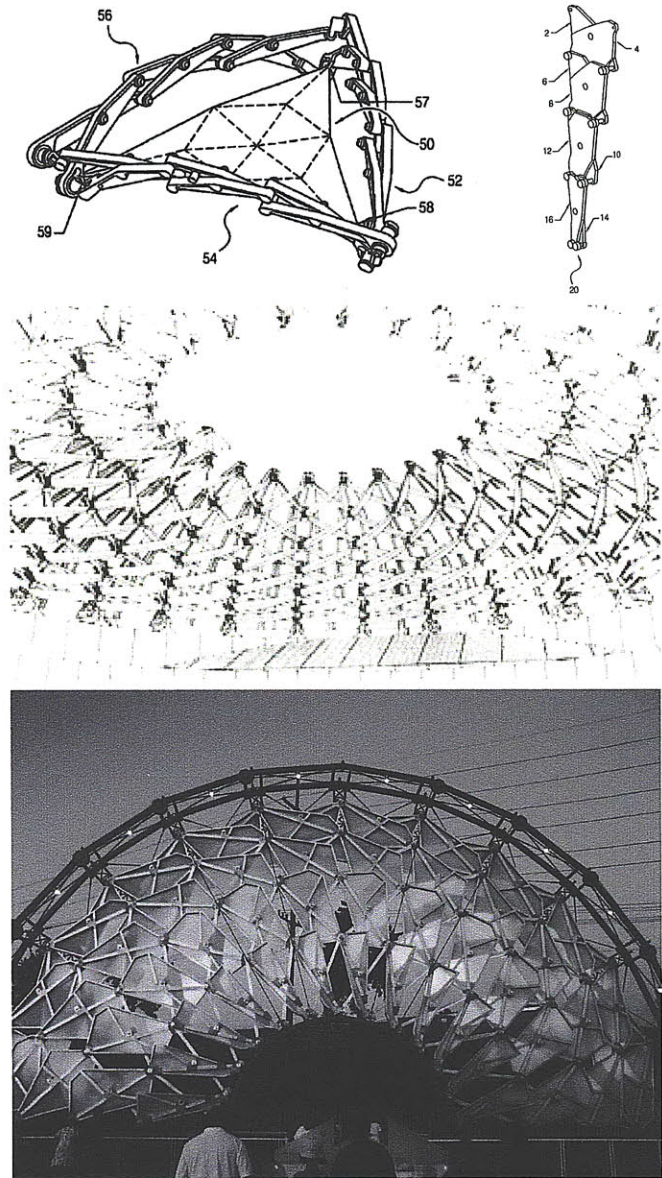


Case Study

Salt Lake City Olympics Arch by Chuck Hoberman (2002)

Chuck Hoberman invented movable and foldable structure that could be used for retractable dome and roof construction. His study started from origami-like paper models that changed shape as they unfold. Hoberman moved on to metal devices with pivoting members interlaced in crescent or hexagonal shapes, that allowed the devices to balloon outward and form a structural sphere. Over the years, Hoberman has continually refined the mechanics of his devices, earning six patents for folding and linkage systems.

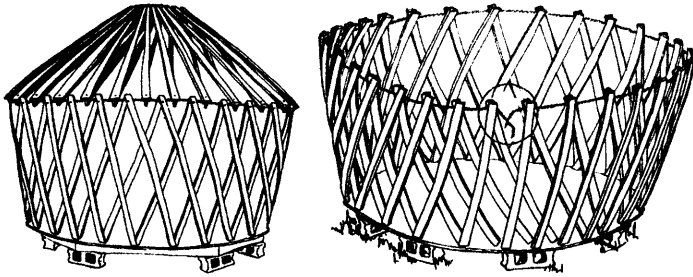
Salt Lake City Olympics Arch by Chuck Hoberman (2002)



A large, light gray number '2' is positioned in the background on the right side of the page.

Design

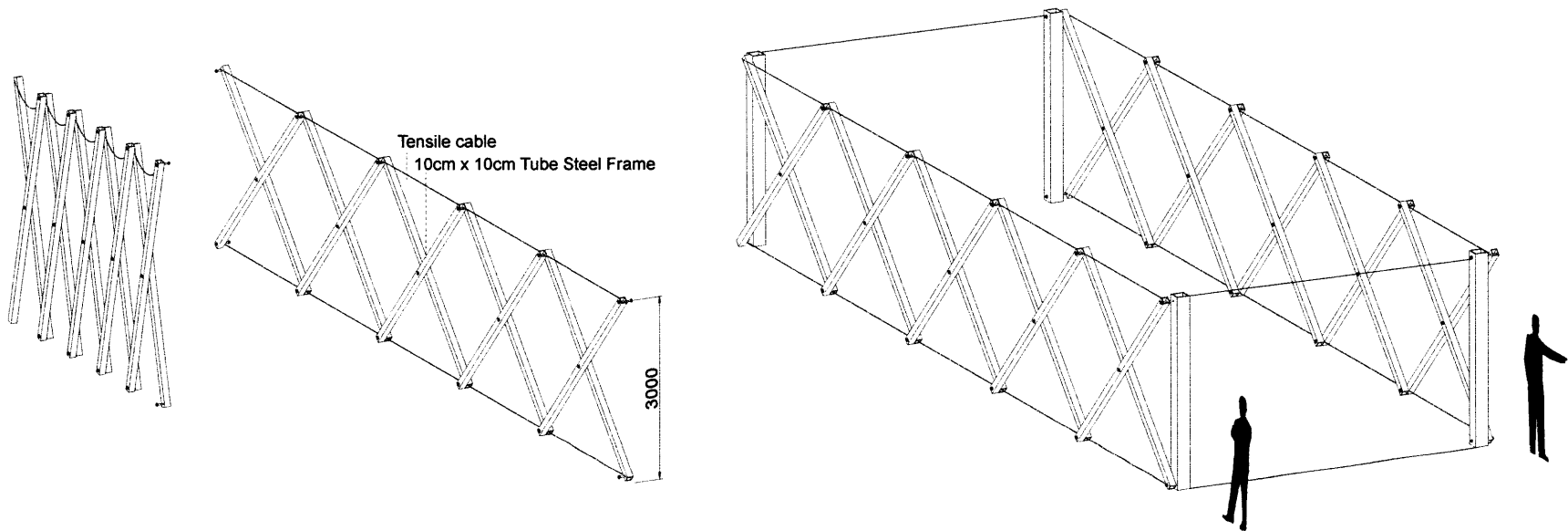
Foldable Structure



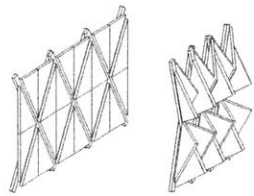
Case Study-Mongolian yurts

The Mongolian yurt is a precedent of a foldable structure that is easily transportable and becomes solid once it is set up. The wall is made from strips that have a scissor joint, forming diagonal truss bracing around the circular perimeter of the house and tightened through a tension band. Felt is used to make a warm and weatherproof covering for a yurt.

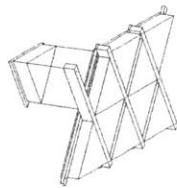
Scissor structure applied for the wall of a house



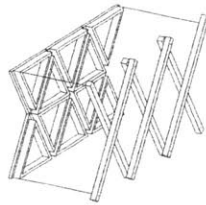
Study for Cladding and the Use of Scissor Structure



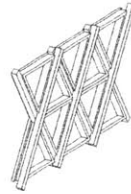
Foldable panels for light control



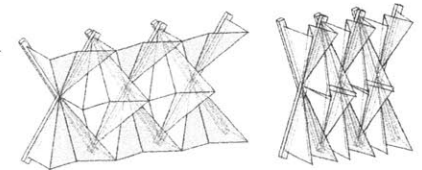
Insulated wall as a jig



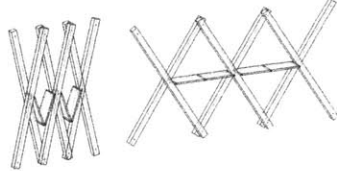
Bookshelf & window frame as a jig



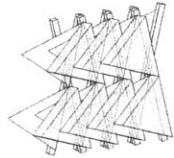
Foldable cladding
for light control



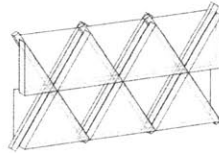
Light and insulation control



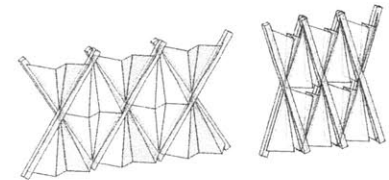
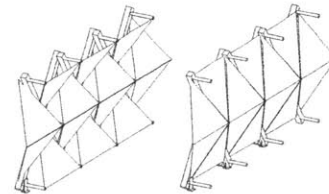
Foldable storage and foldable table



Sliding diaphragms

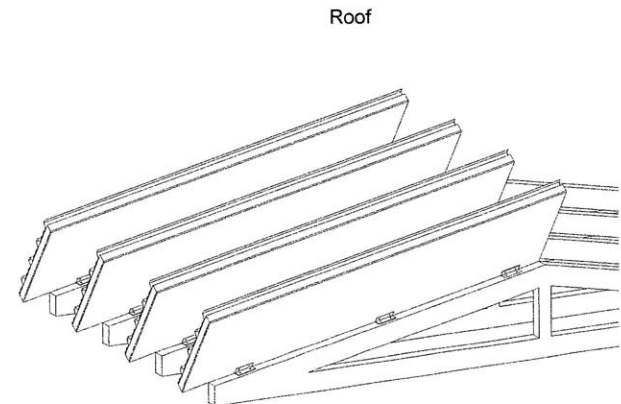
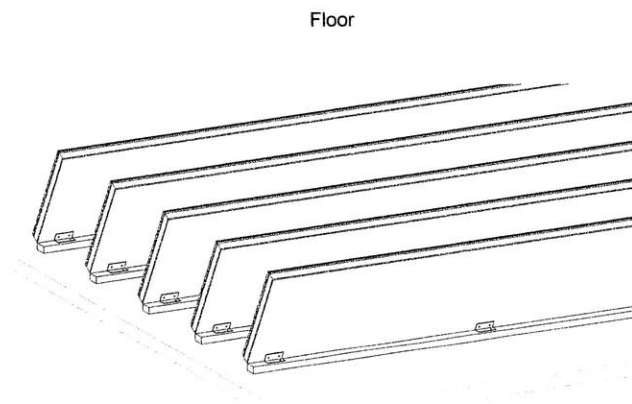
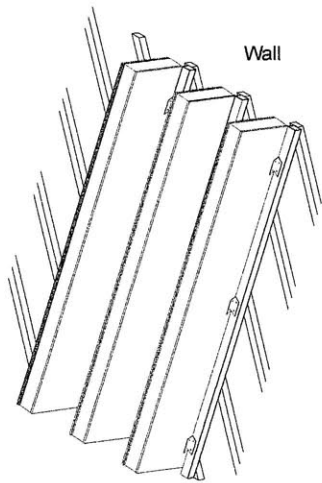
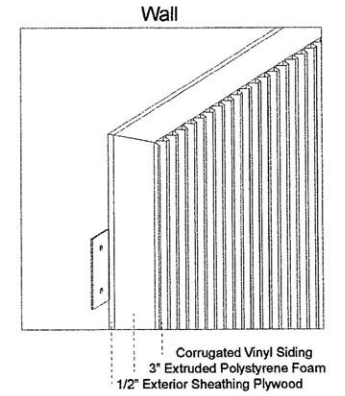
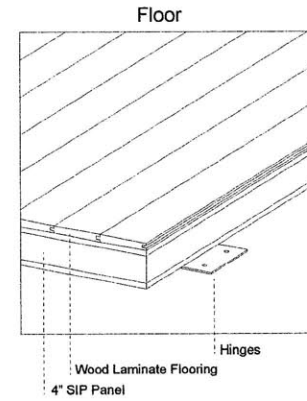
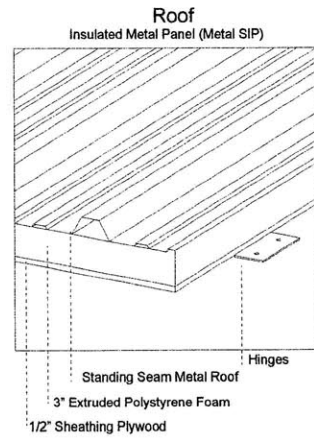
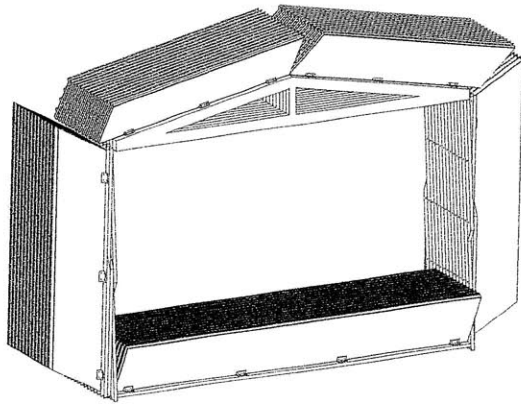


Shading device

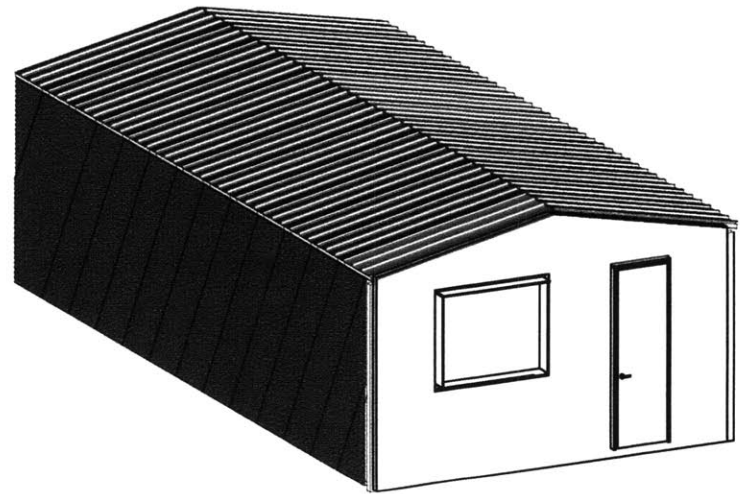
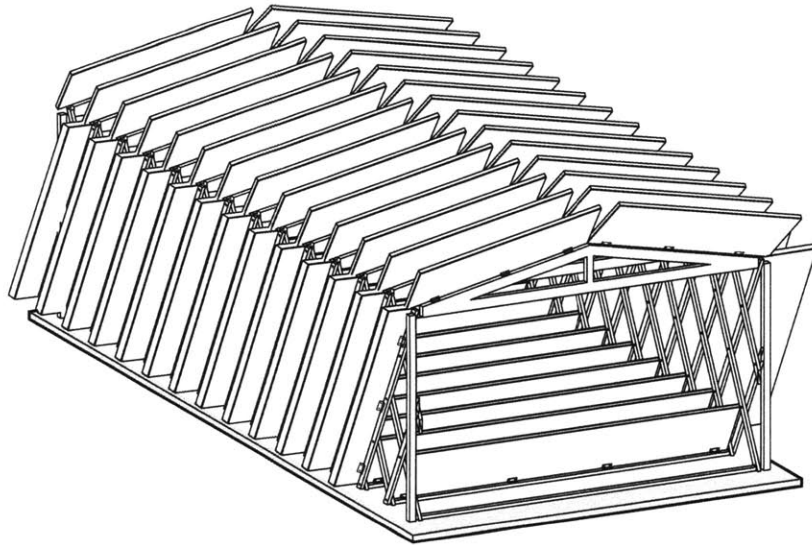
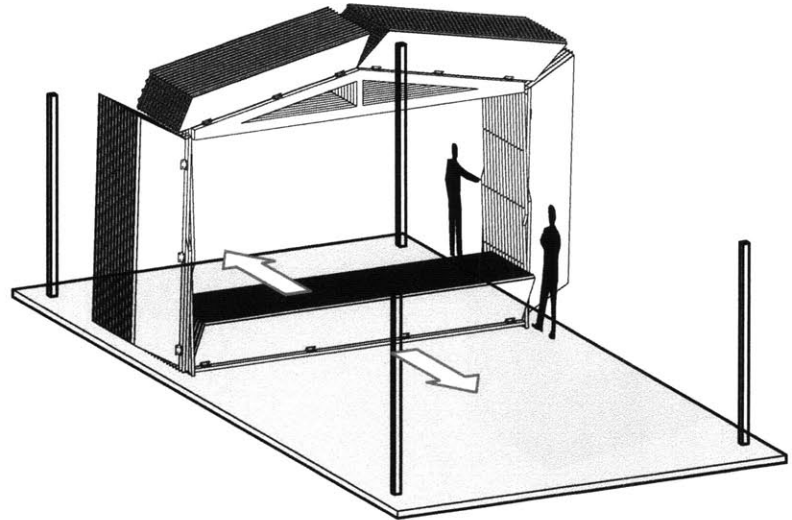
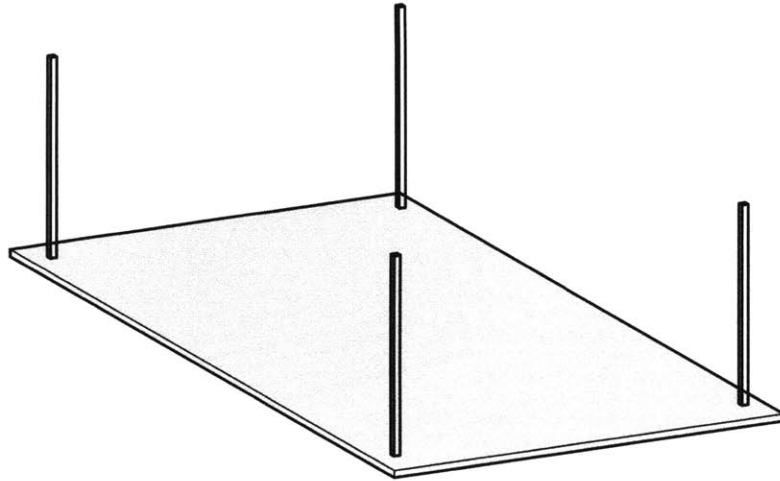


Light and insulation control

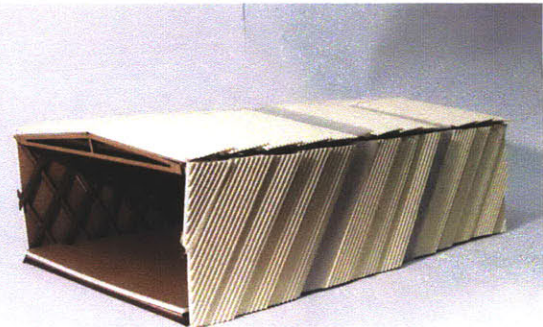
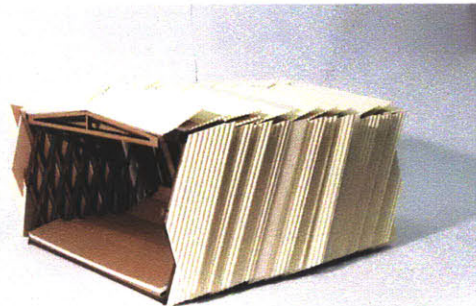
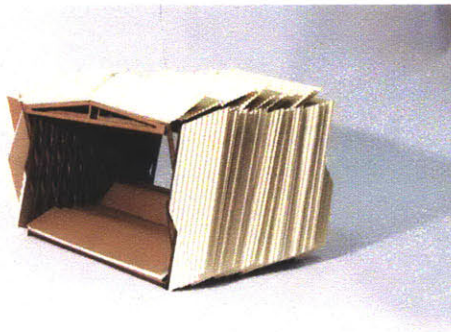
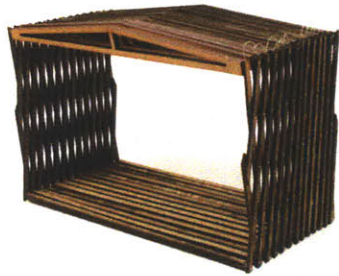
Study 1. Expandable House through Hinged Cladding



Construction Sequence



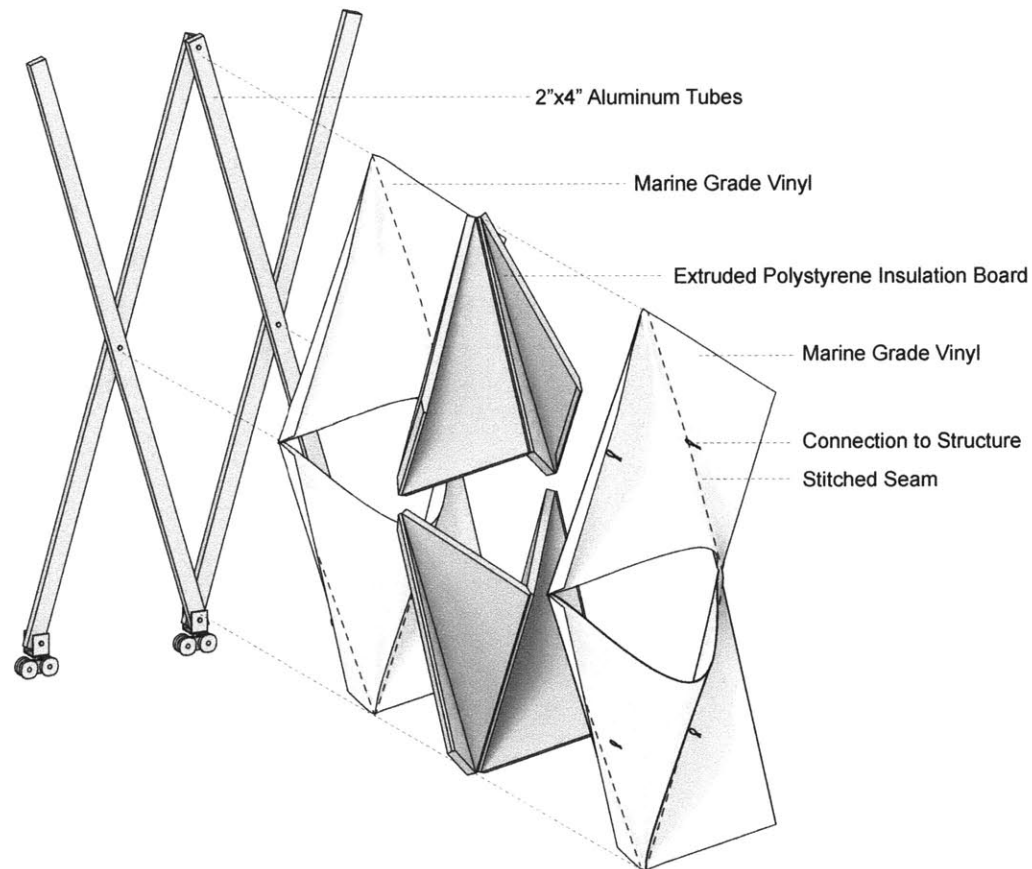
Study Model



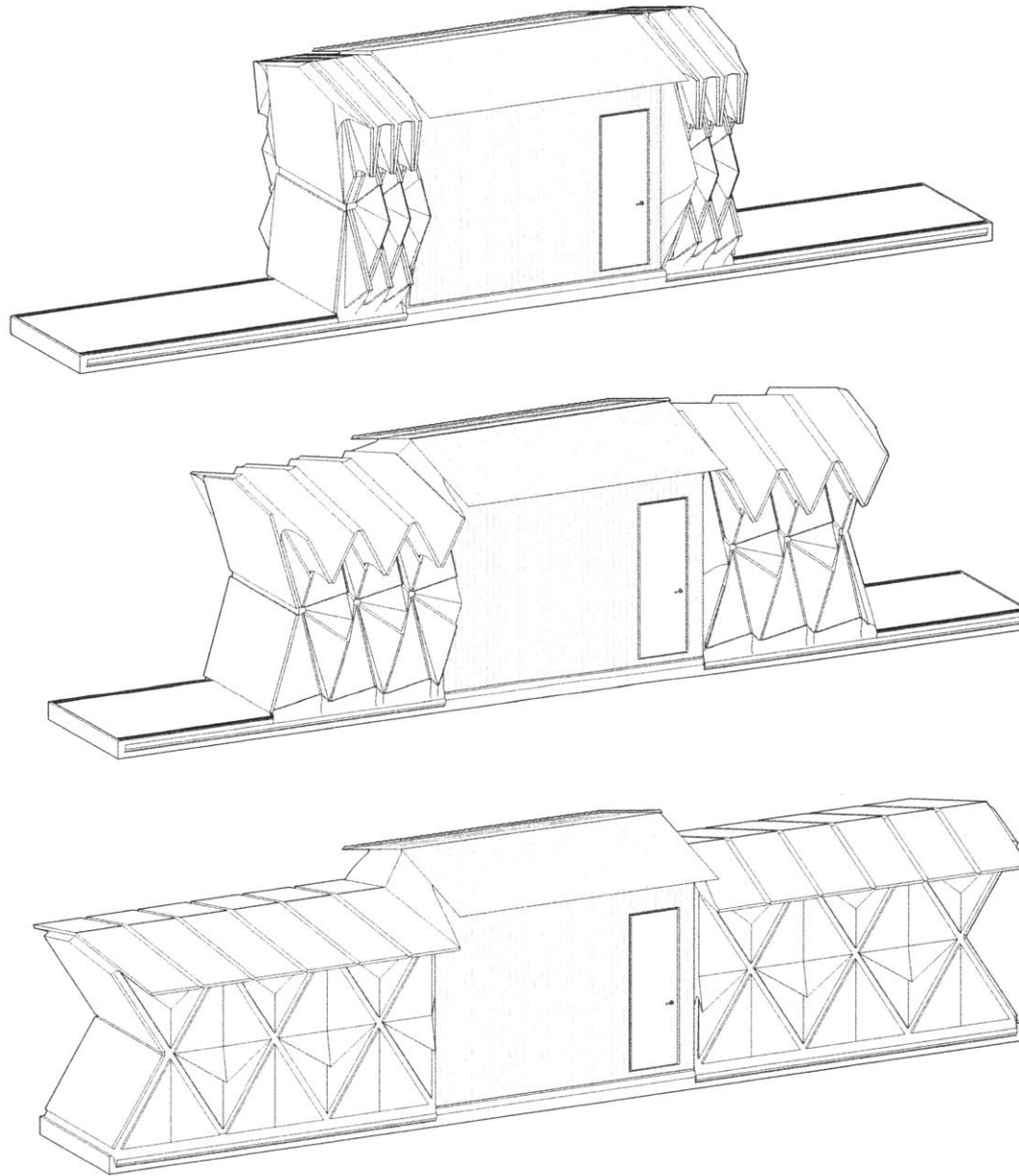
The first study model of the foldable house used a scissor structure and hinged envelope as a fin.
The main issue with this house was that the accordion structure only provided instant assemble of the house and lacks the expandable feature could be occupied differently by users and suggest a new way of living.
The next study model suggests cladding that folds according to the structure and affects the light, ventilation, and space.

Study 2. Expandable House through Origami-folded Cladding

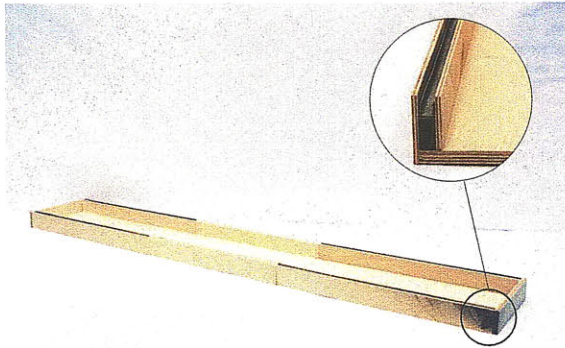
The second study model attaches an origami envelope to the scissor structure so that the envelope contracts according to the movement of the structure. The flexibility of the folds and durability of the surface are achieved through laminating rigid foam insulation between weatherproof vinyl fabrics.



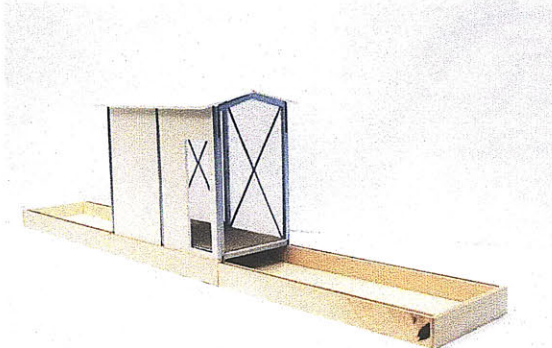
Foldable House



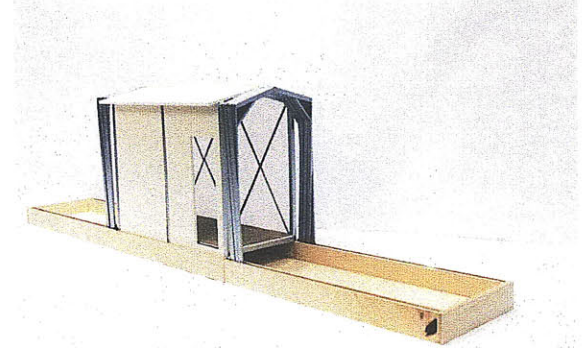
Construction Sequence



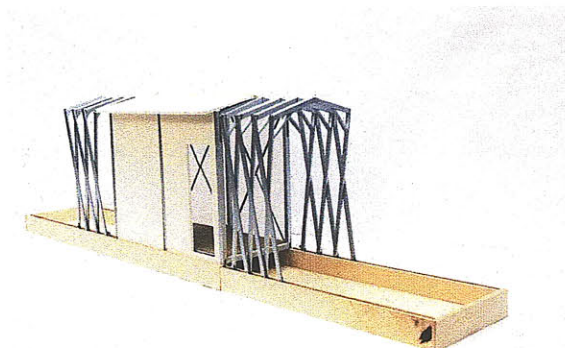
Installation of the foundation plate with C channel



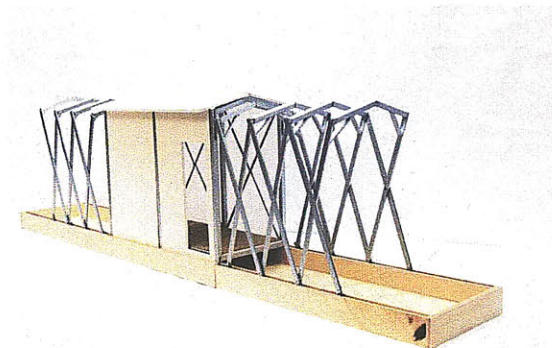
Installation of the core unit



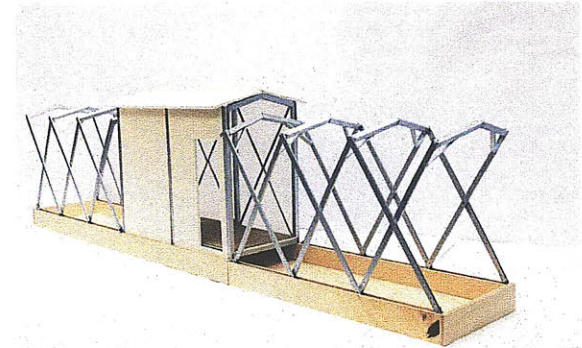
Installation of the expandable structure on the channel



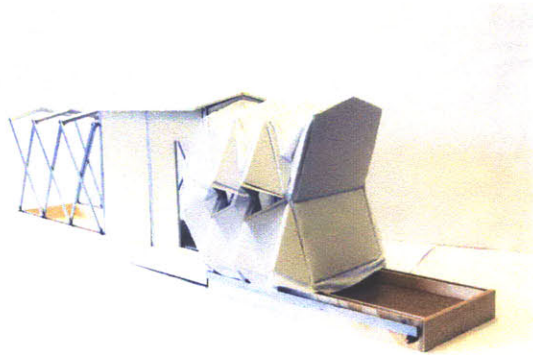
Expansion of the structure ①



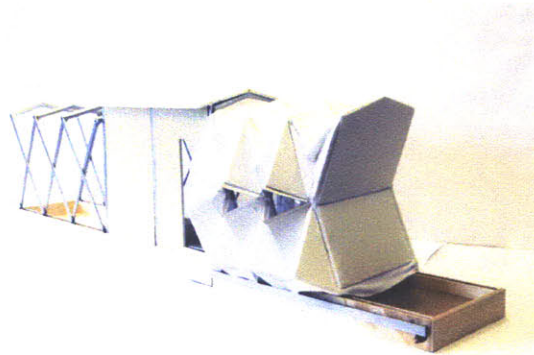
Expansion of the structure ②



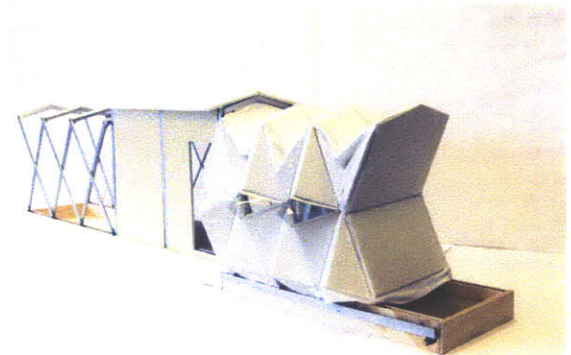
Expansion of the structure ③



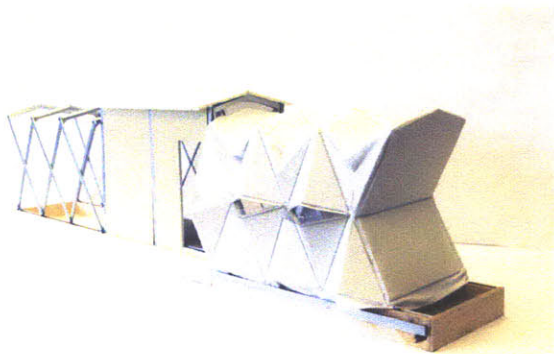
Expansion of the envelope ①



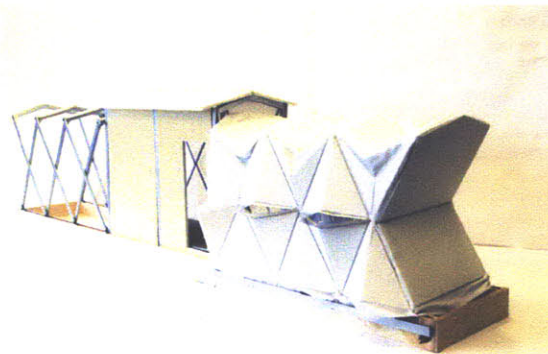
Expansion of the envelope ②



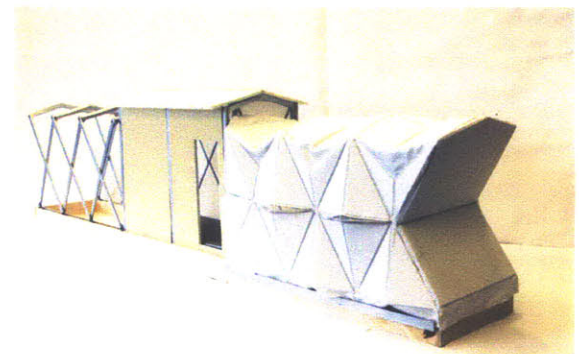
Expansion of the envelope ③



Expansion of the envelope ④

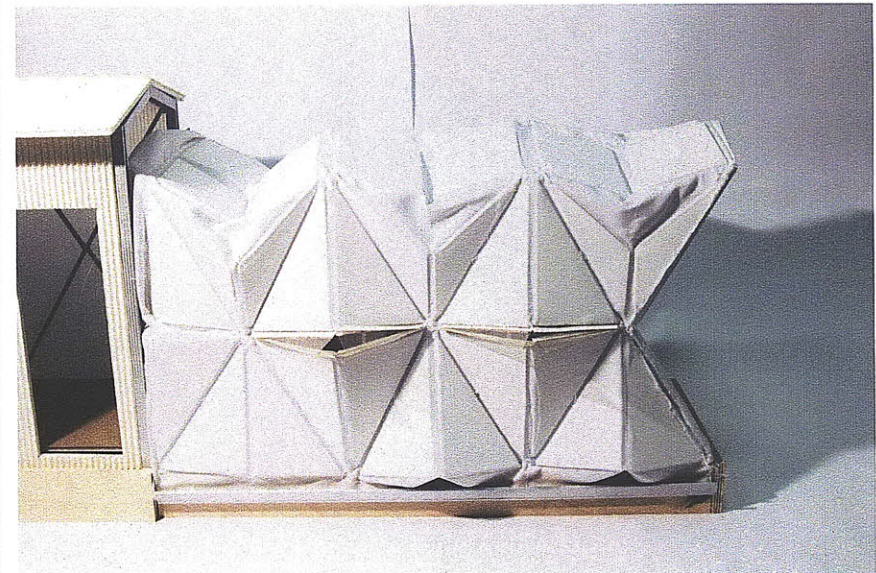
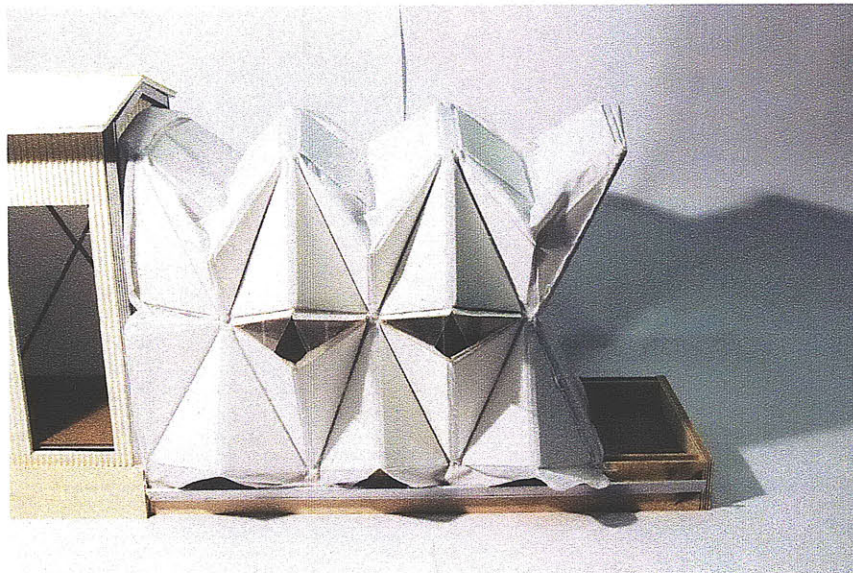
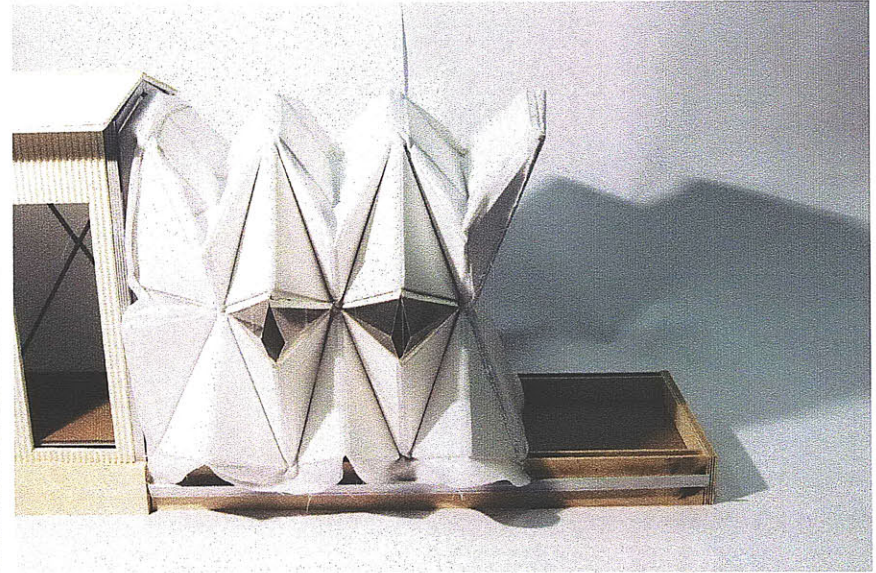
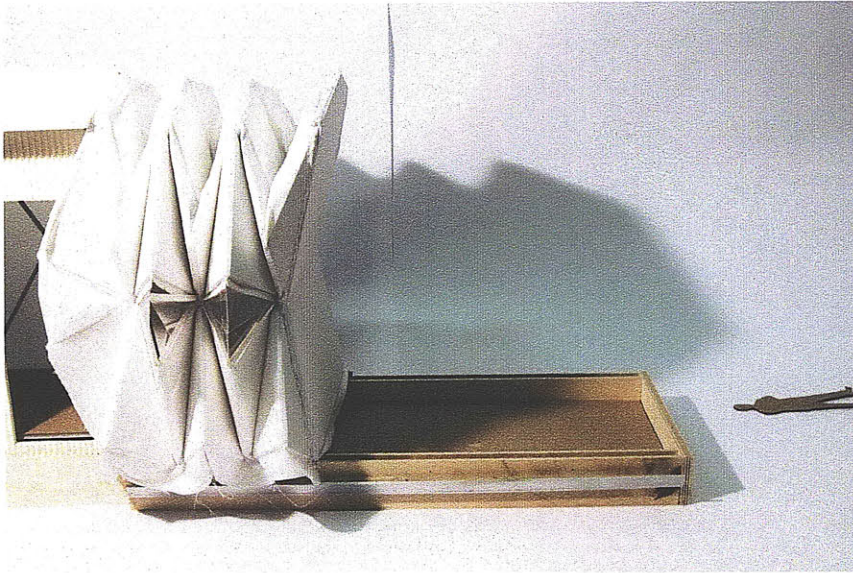


Expansion of the envelope ⑤

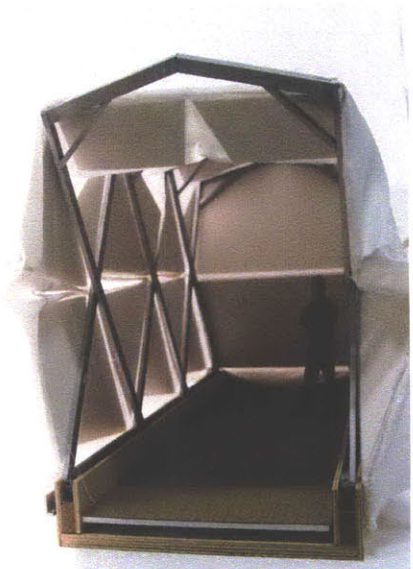
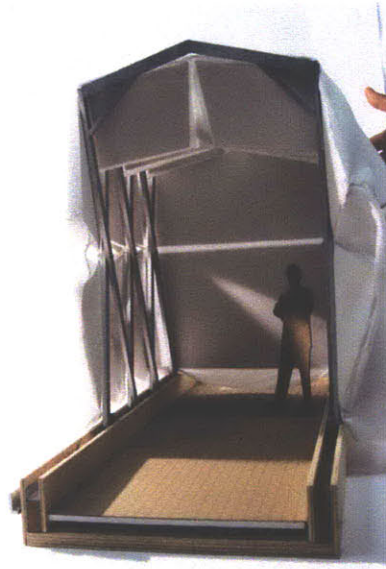
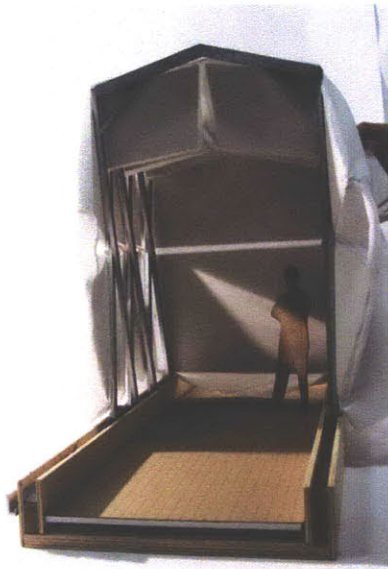


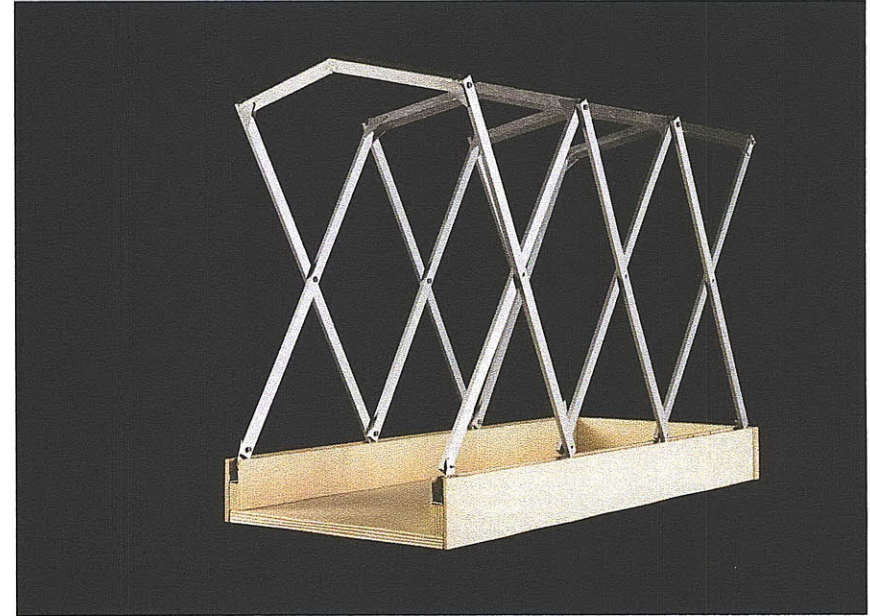
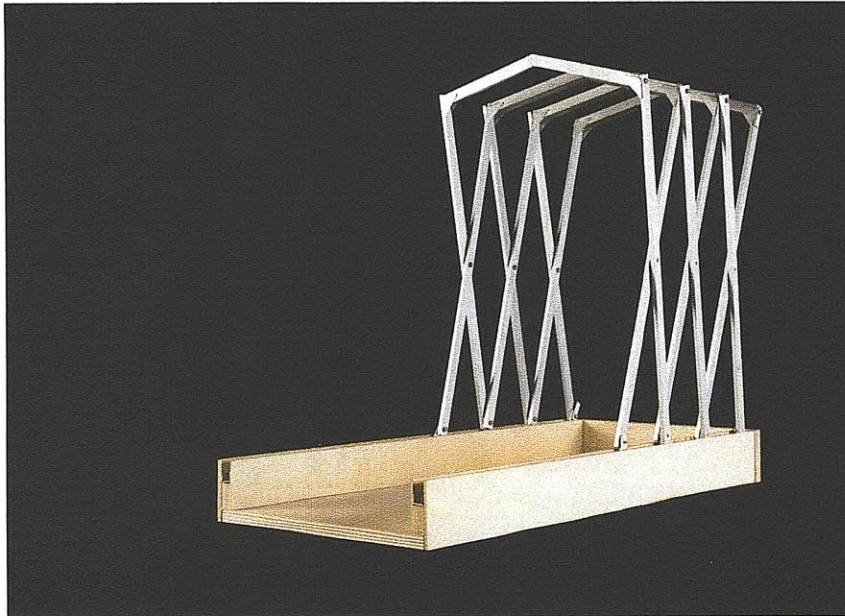
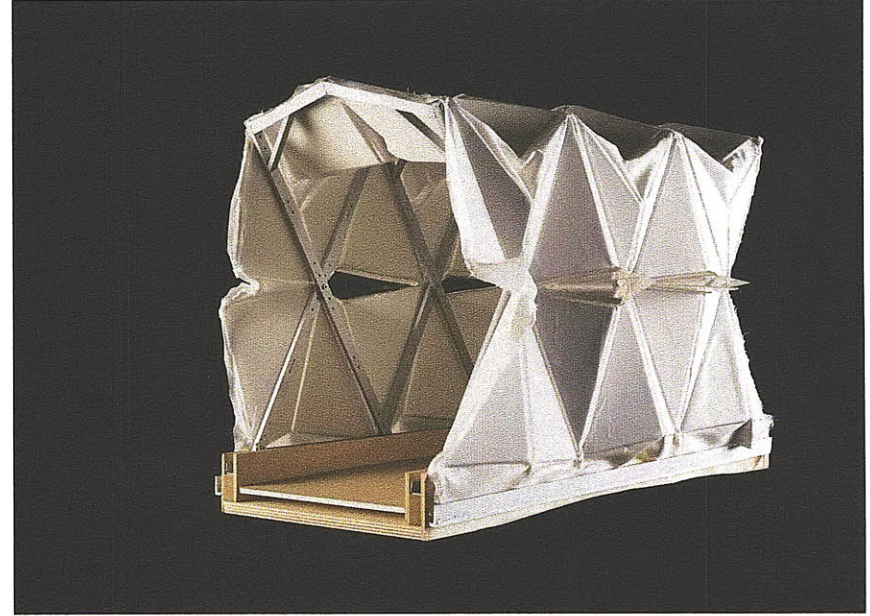
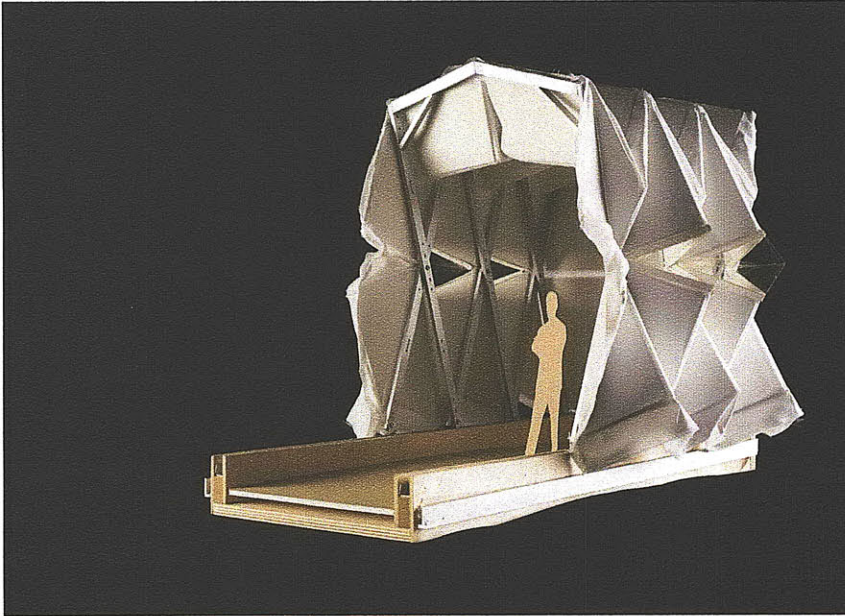
Expansion of the envelope ⑥

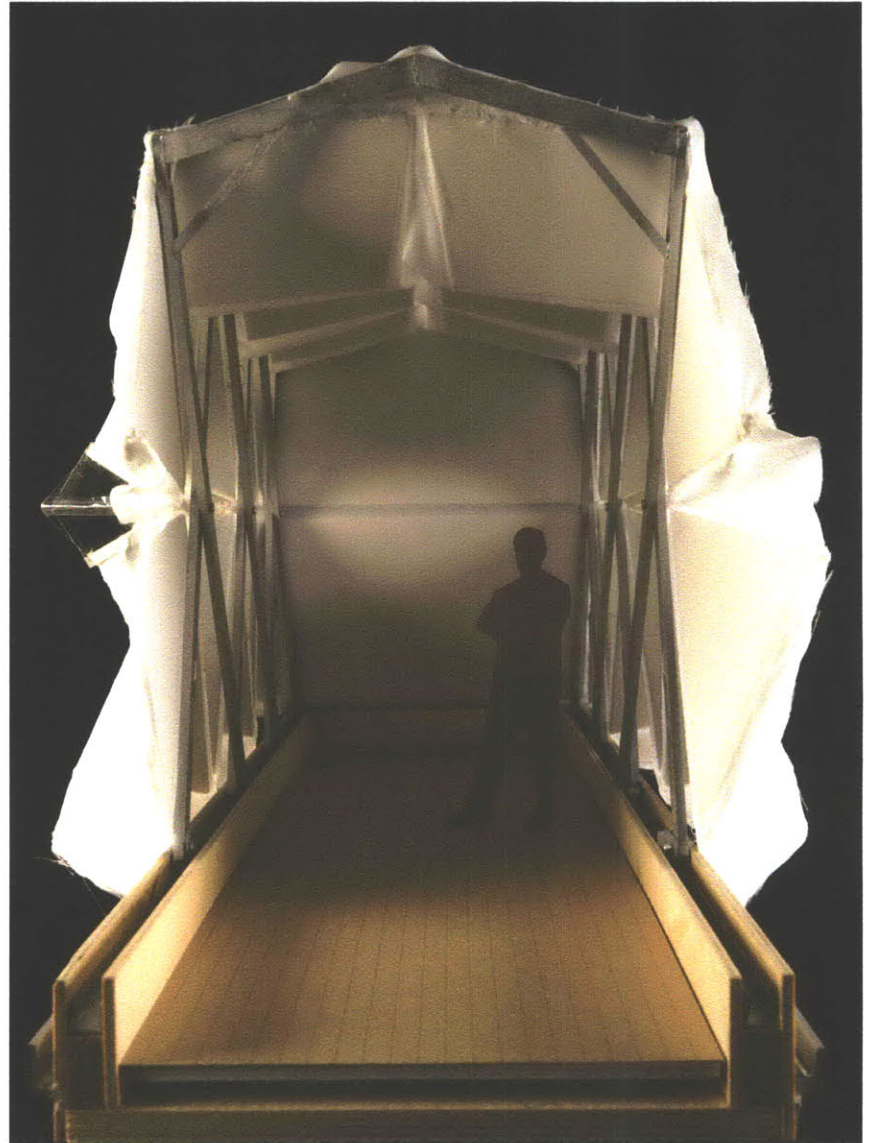
Expansion Sequence



Expansion Sequence: Interior

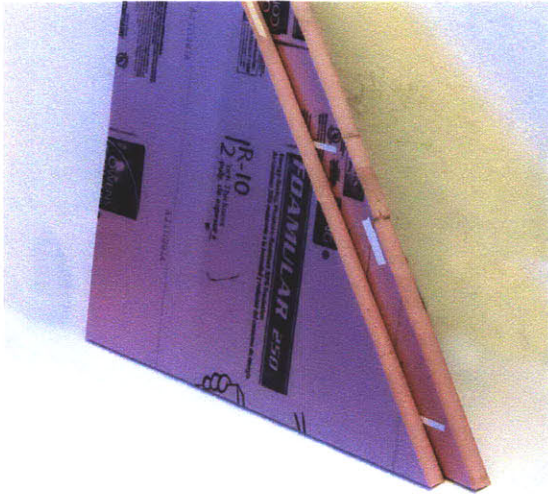






Drawings & Fabrication

Material



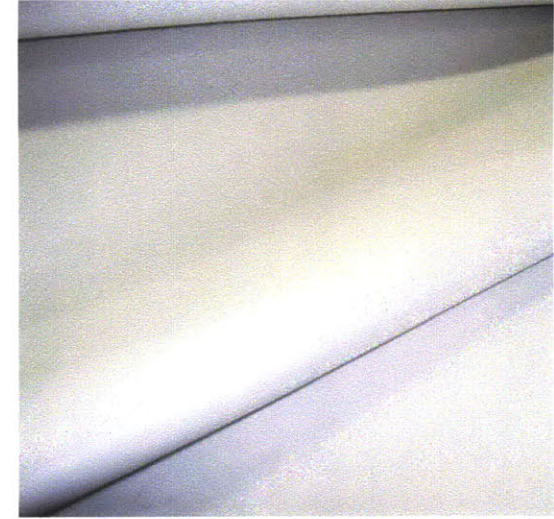
Extruded Polystyrene Foam

Extruded polystyrene foam (XPS) offers improved surface roughness and higher stiffness and reduced thermal conductivity. Because of its high compressive strength and water resistance, XPS is often used below grade to insulate slabs and foundation walls. The density range is about 28 – 45 kg/m³. Thermal resistivity is usually about 35 m²·K/W (or R-5 per inch in).



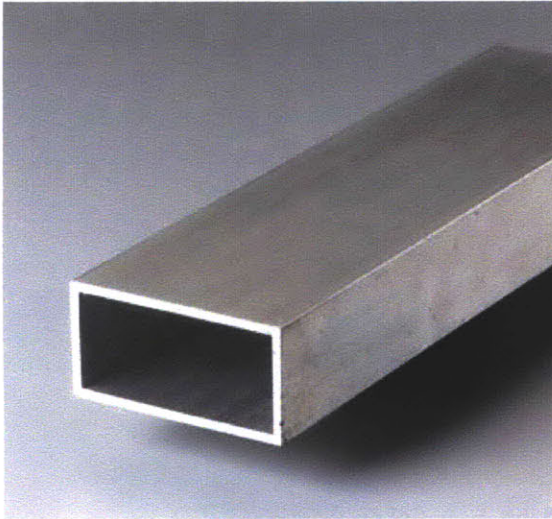
Marine Grade Vinyl Fabric

Width: 54"
Weight: 30 Ounces Per Linear Yard
Backing: Polyester/Rayon
Abrasion Resistance: 250,000+ Double Rubs
UV Resistance to 500 Hours
Cold Crack: -20 degrees F
Bacterial Resistant per AATCC 147
Mildew Resistant per ASTM G21
Sulfide Stain Resistant, Oil Resistant
Heat Sealable



Flammability Requirements:

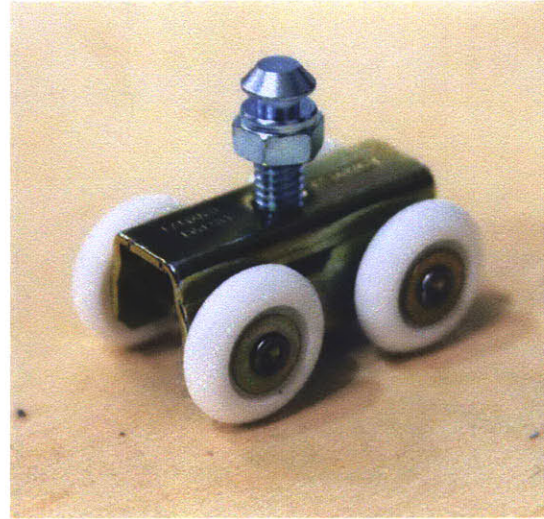
FMVSS 302
California Flammability Regulation
(Bulletin 117, Section E)
UFAC Class 1
BIFMA Class A



Aluminum Rectangular Tube (Alloy 6061)

Ultimate Tensile Strength, psi 45,000
Yield Strength, psi 40,000
Brinell Hardness 95
Rockwell Hardness B60

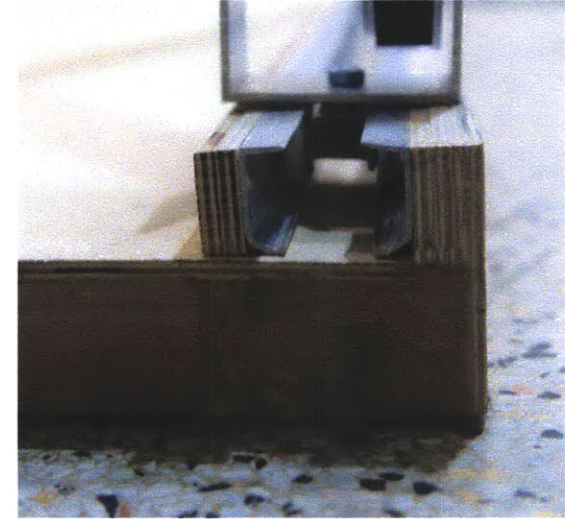
6061 is a heat-treatable grade aluminum widely used in light-to medium-strength structural applications. The alloy has good corrosion resistance and weldability and possesses good formability. It is used in truck bodies and frames, and towers.



Roller Track Systems for Doors Hanger with Plastic Wheels

Wheel diameter: 2 1/8"
Hanger width: 1 3/4"
Hanger height: 5 1/16"

(150-lb. Capacity set for 1:2 mockup)



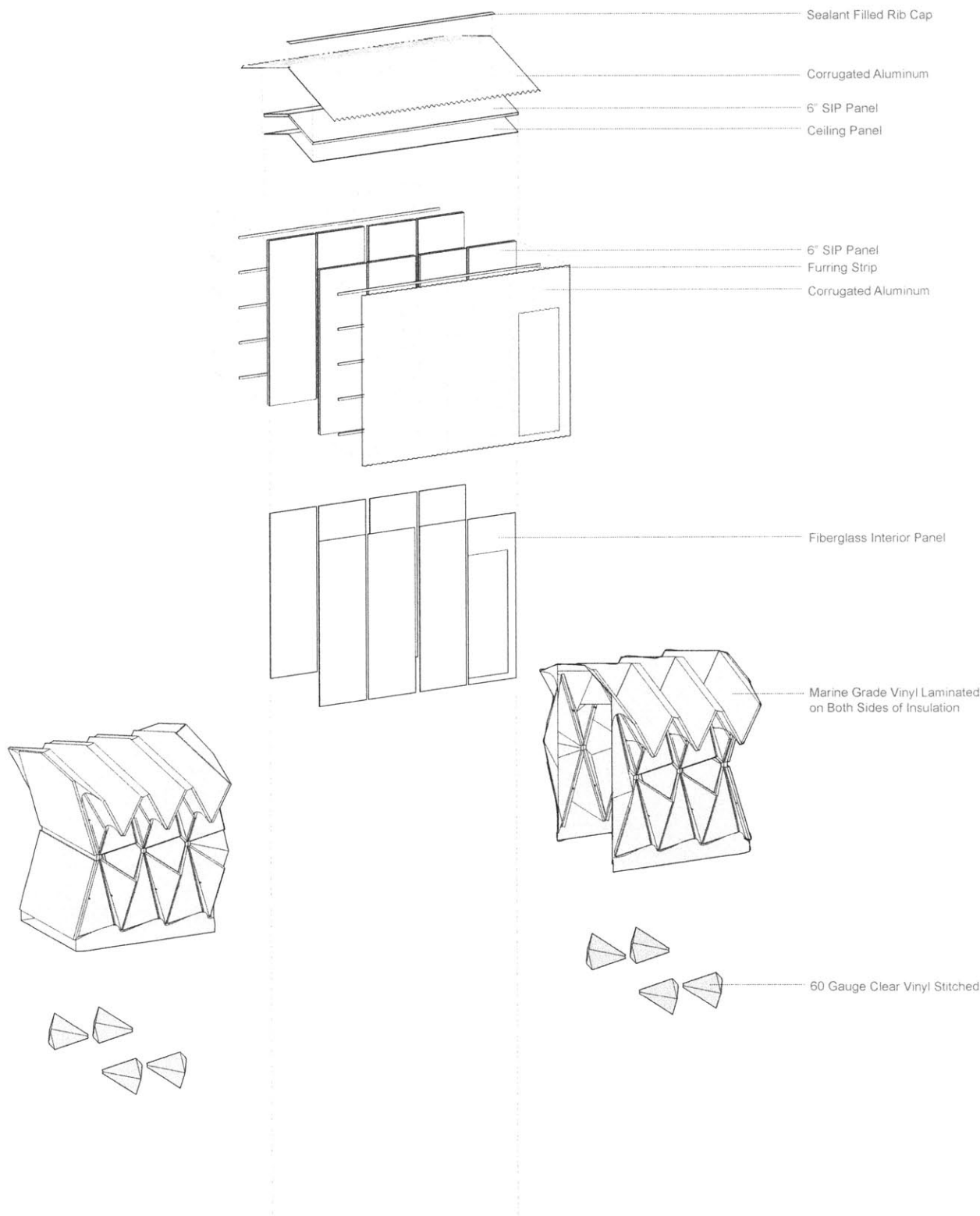
Roller Track Systems for Doors Aluminum Track

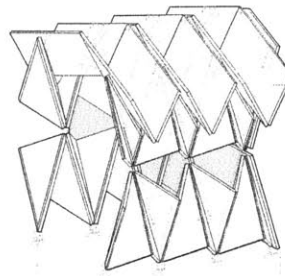
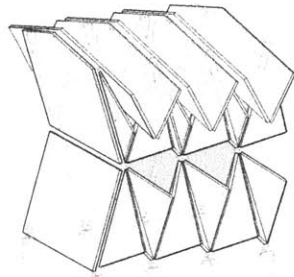
Aluminum thickness 0.056"
Track length: 6 ft.
Track width: 1 13/16"
Track height: 1 3/16"

(150-lb. Capacity set for 1:2 mockup)

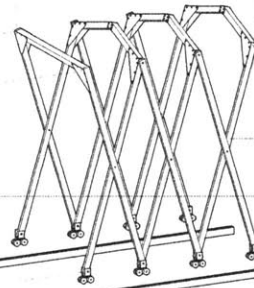
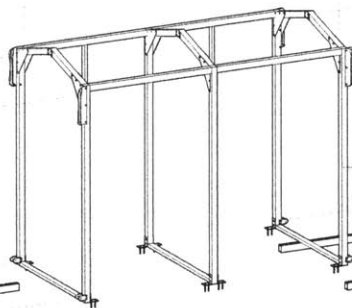
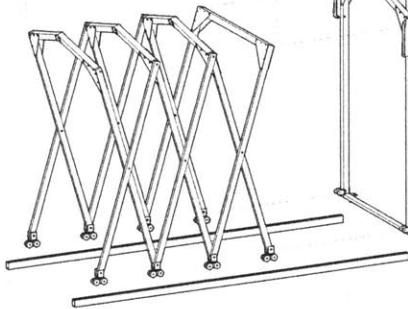
42 **Materials: Exploded Axonometric**

The house is composed of two parts: rigid core and expandable living space.





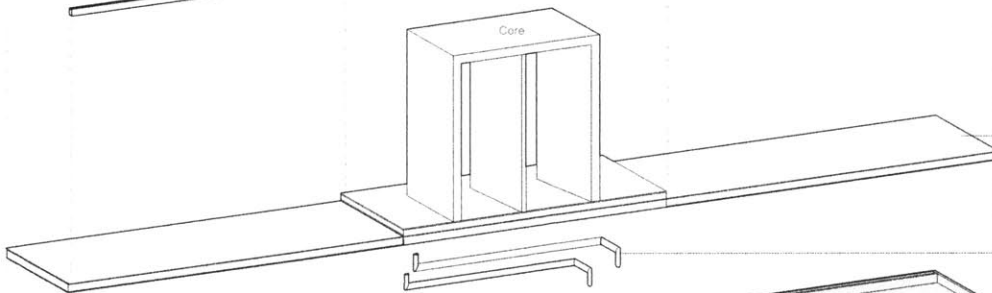
2" Extruded Polystyrene
Insulation



12" x 2" x 4" x 1/8"
Aluminum Rectangular Tubes

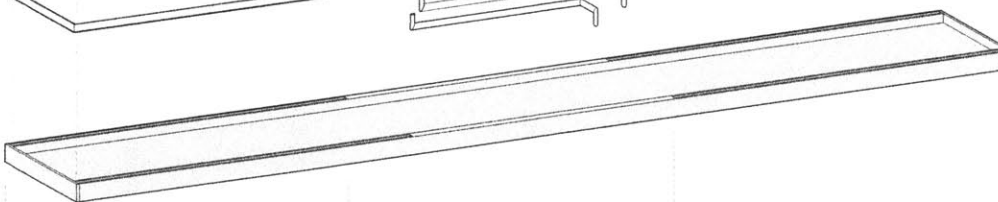
12" x 4" x 4" x 1/8"
Aluminum Rectangular Tubes

3" Ø Wheel
Track for Rollers

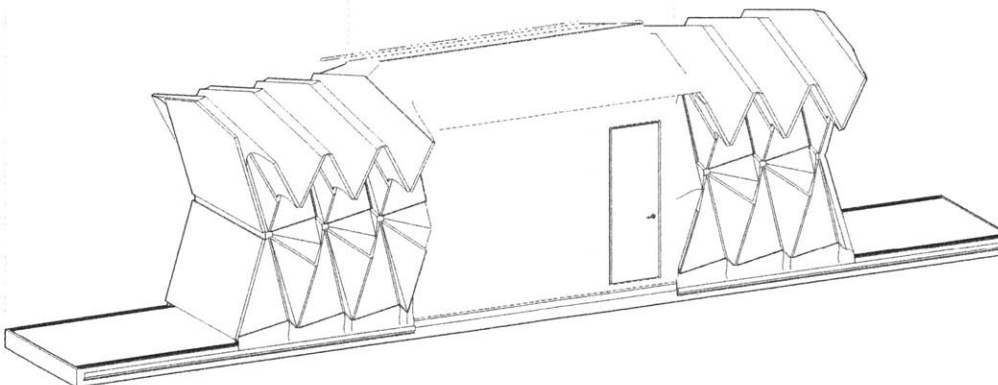


6" SIP Panel + Vinyl Flooring

Gas and Water Pipe under Core

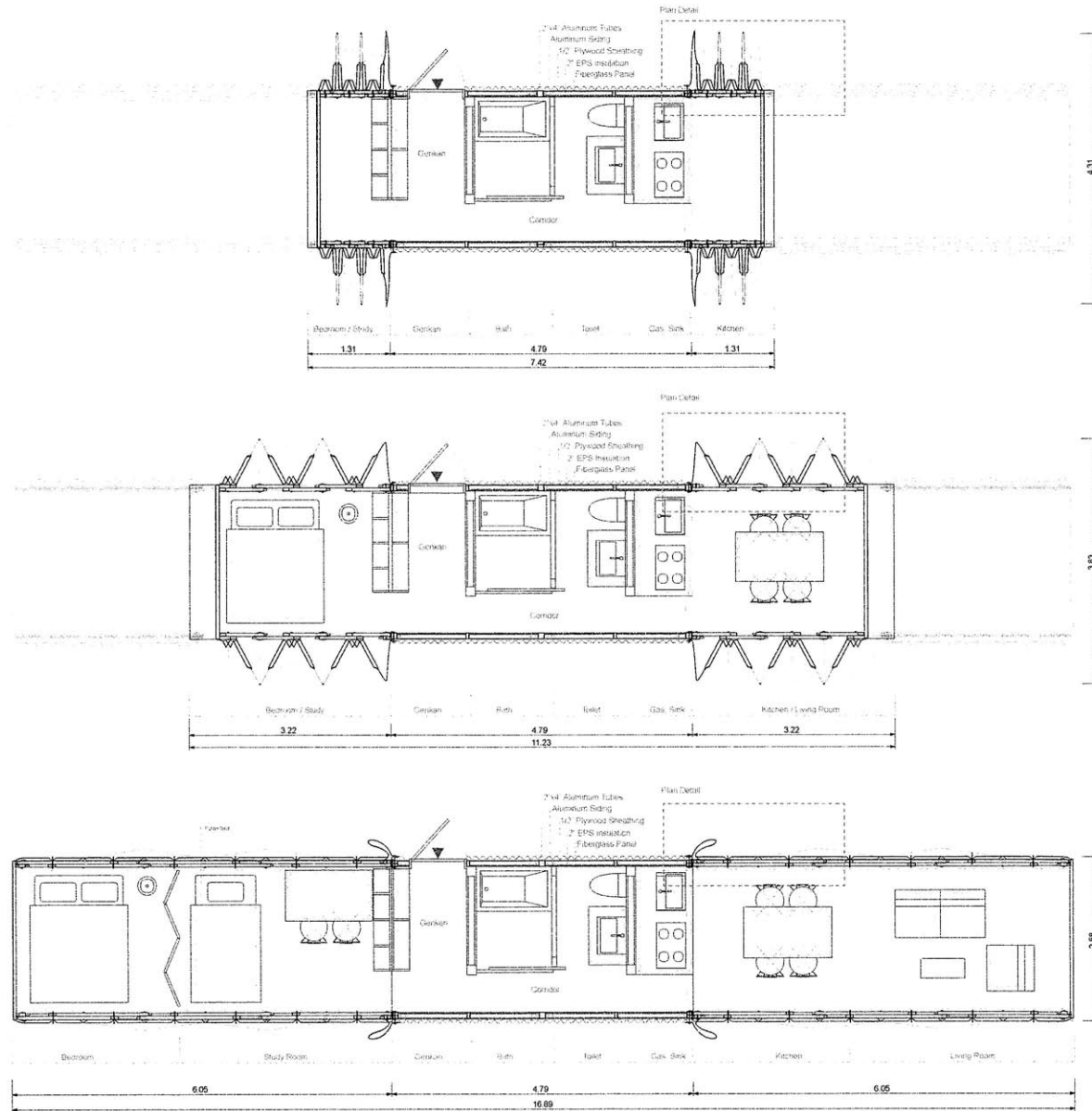


30cm Concrete Foundation



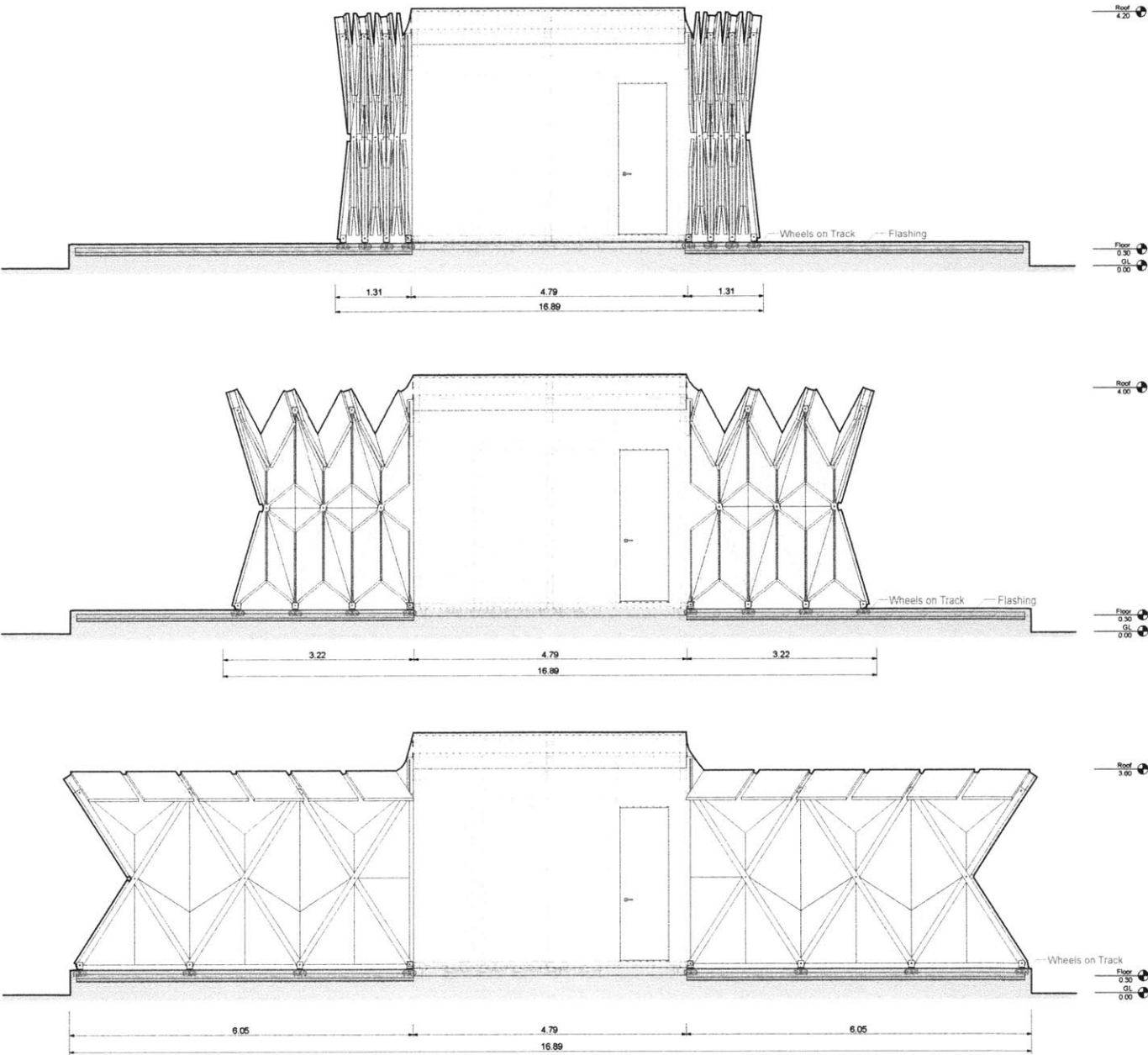
Plan

Scale = 1:100



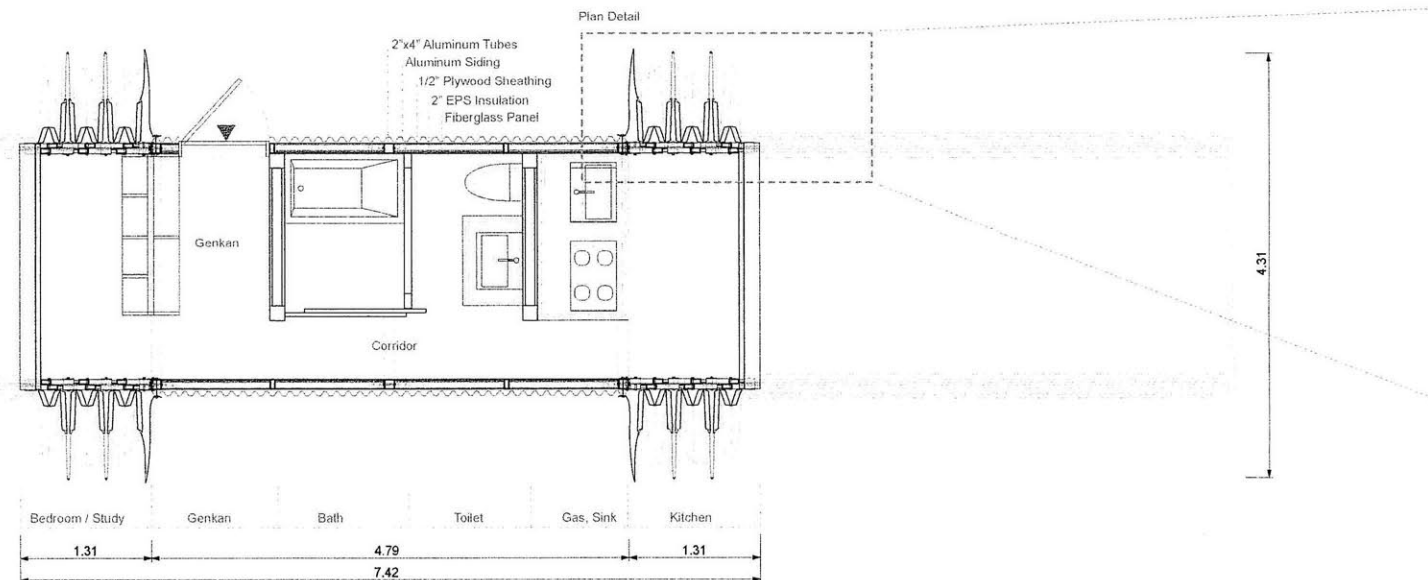
Elevation

Scale = 1:100



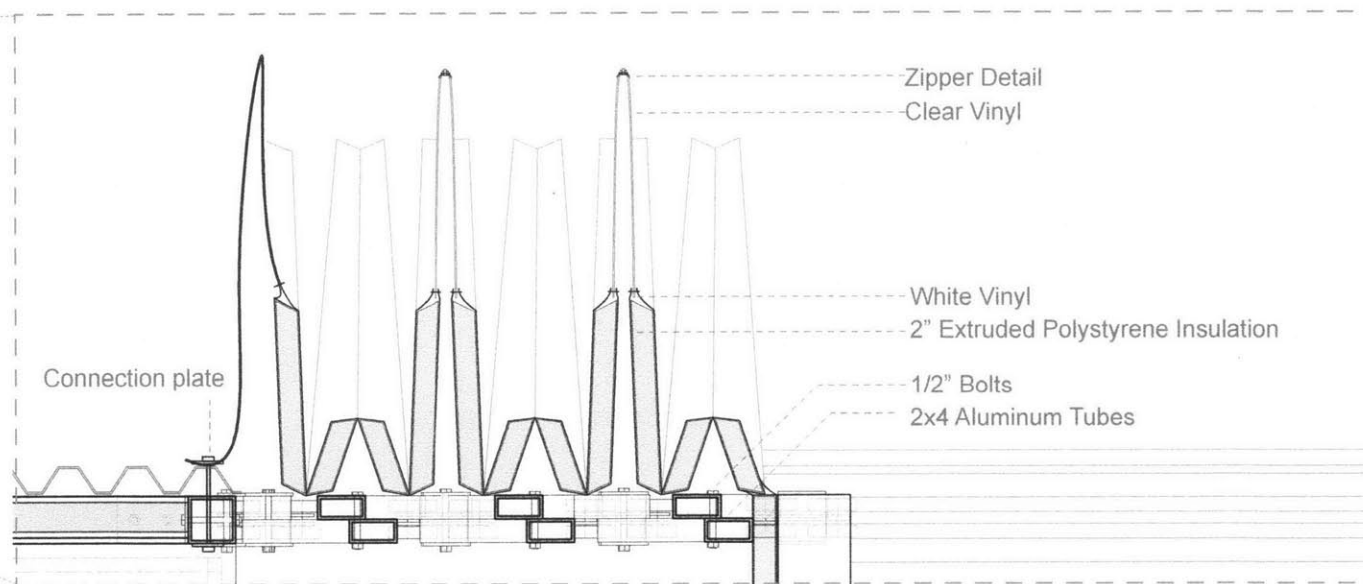
Plan

Scale = 1:80



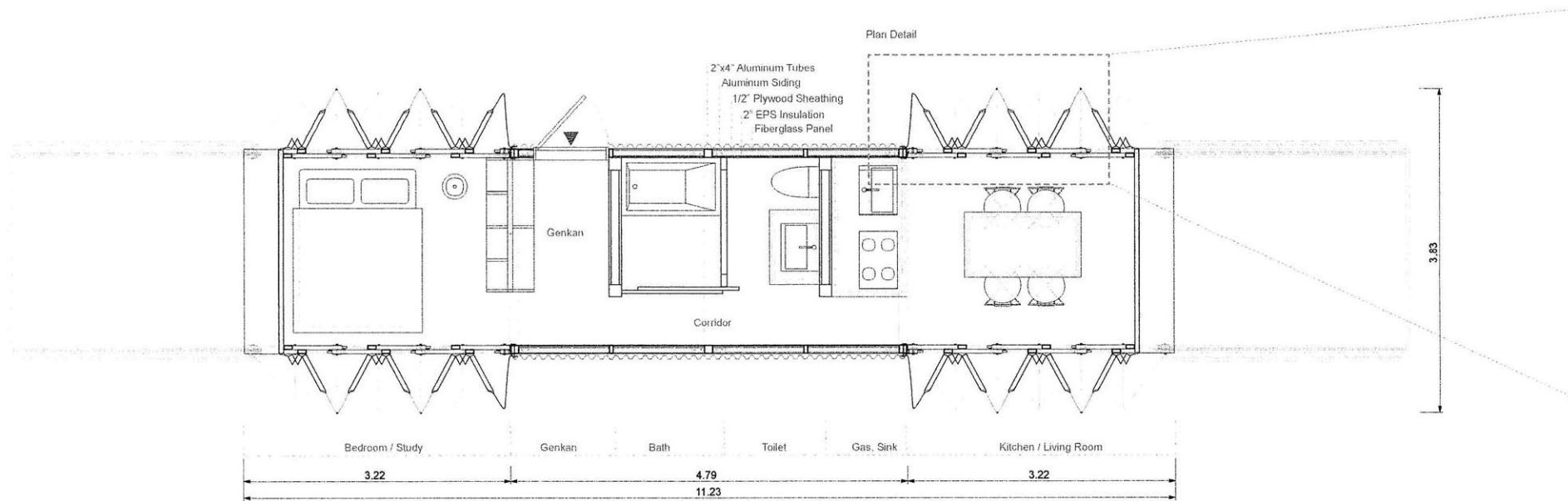
Plan Detail

Scale = 1:30



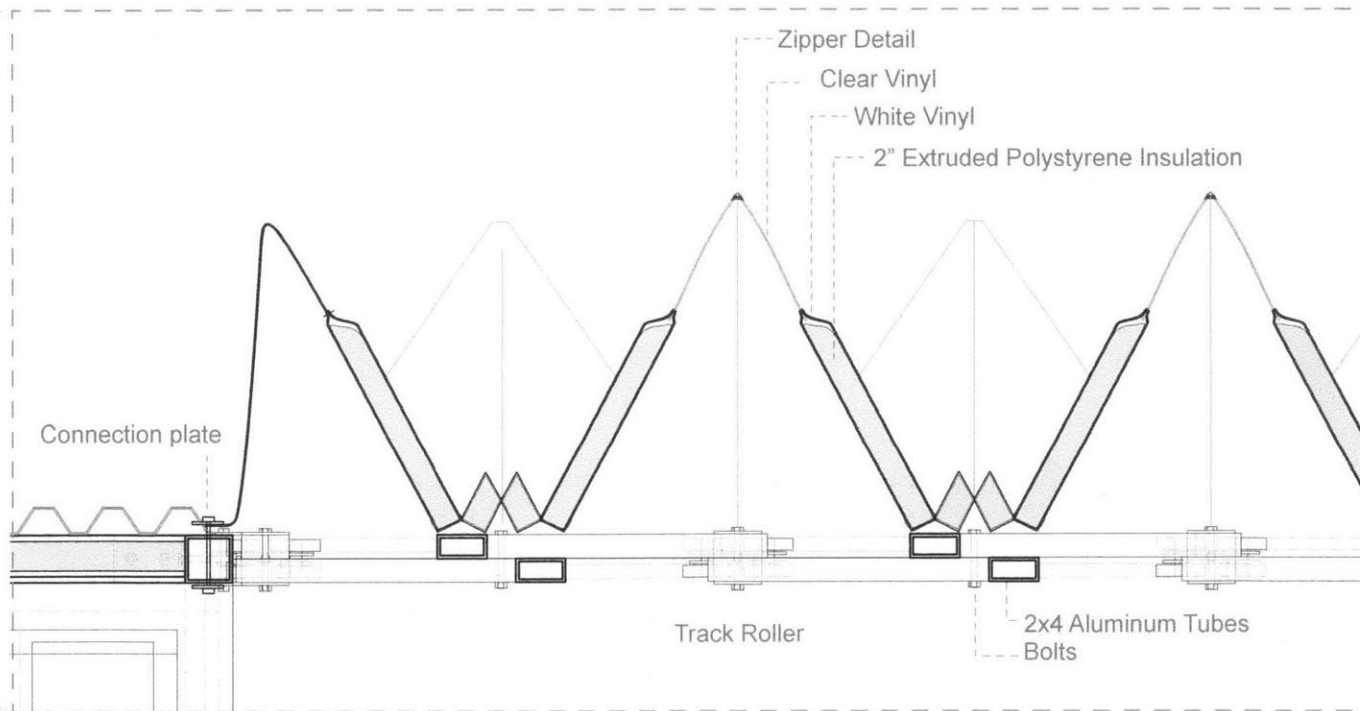
Plan

Scale = 1:80



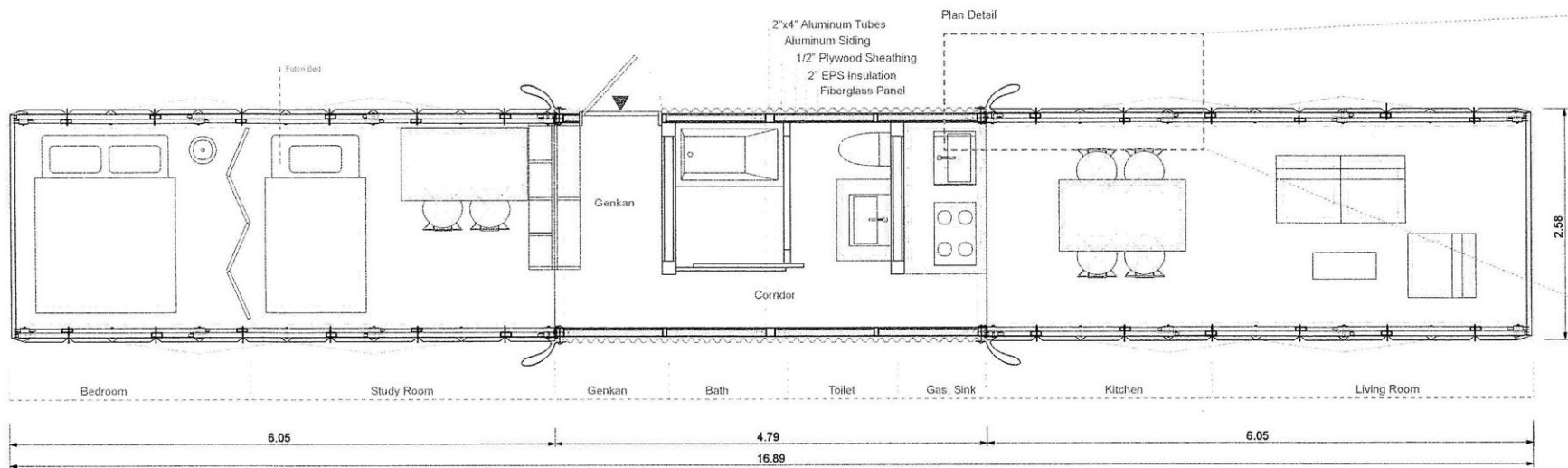
Plan Detail

Scale = 1:30



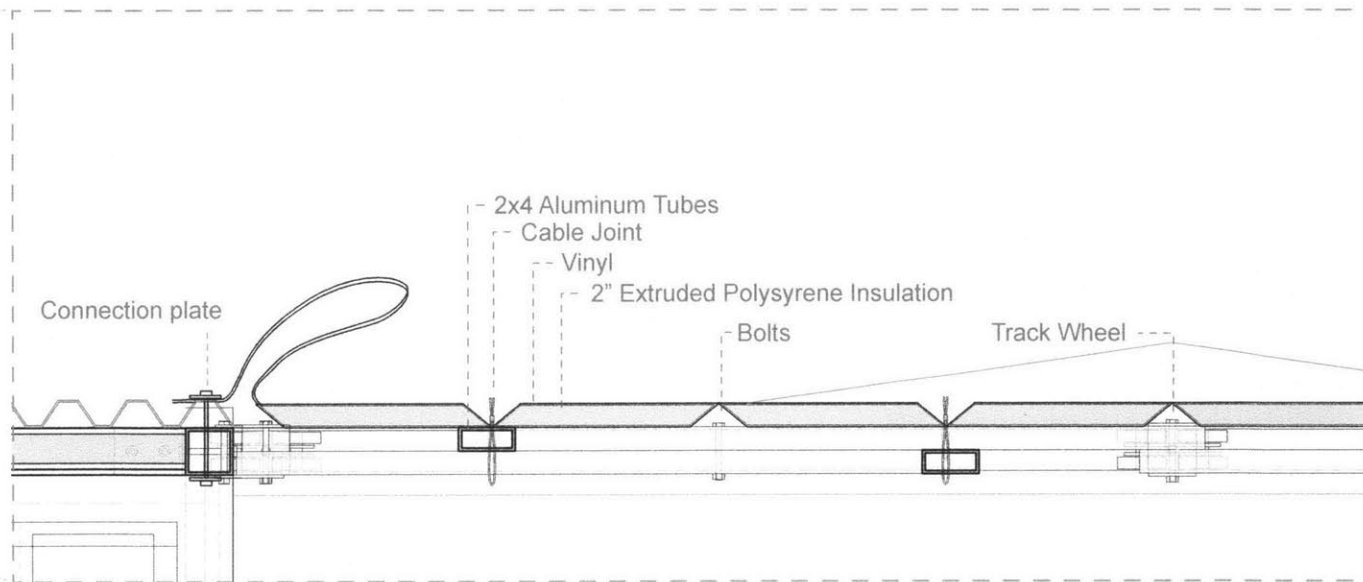
Plan

Scale = 1:80

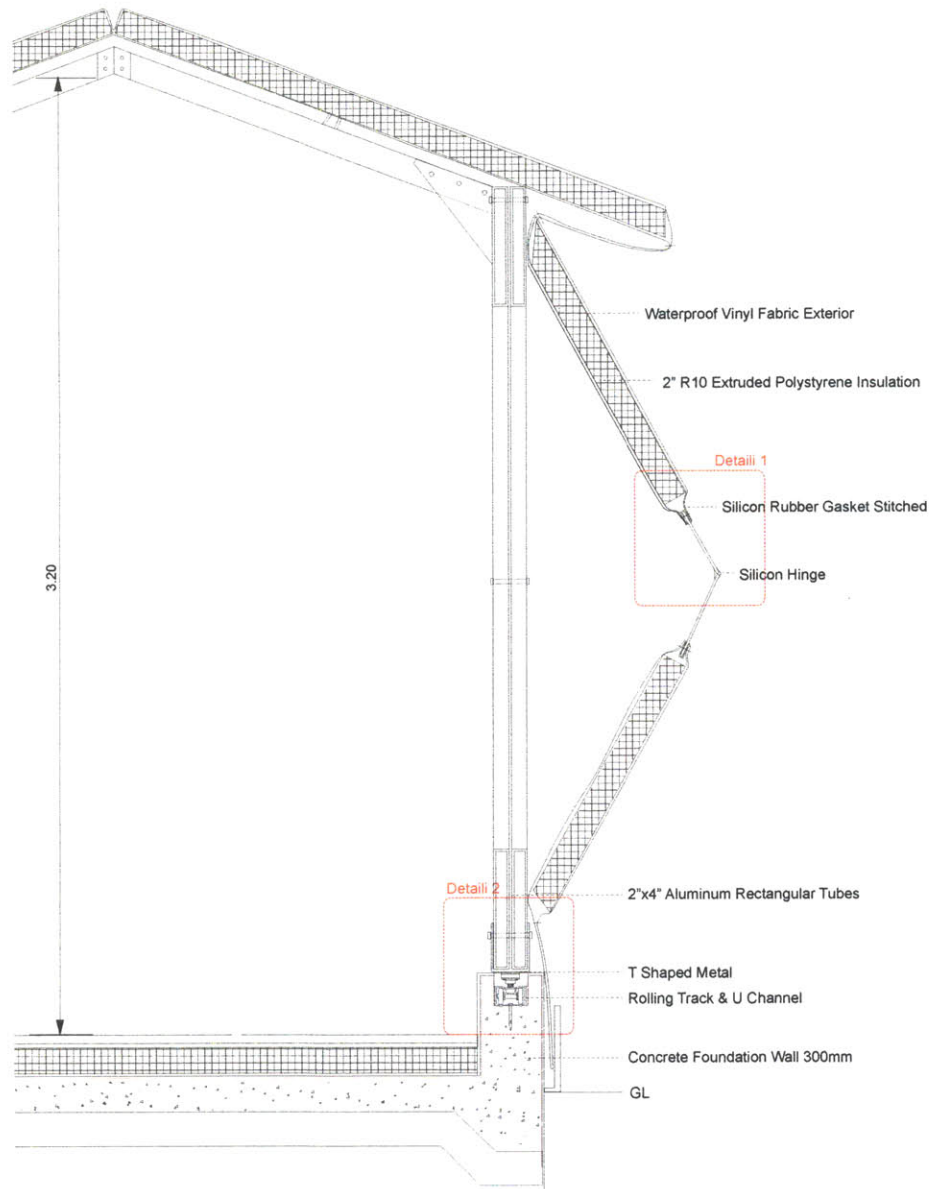


Plan Detail

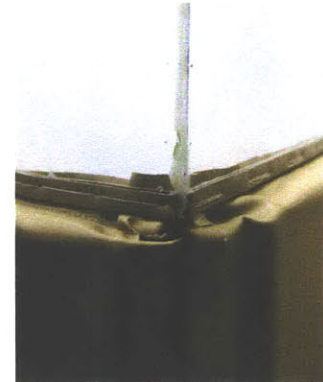
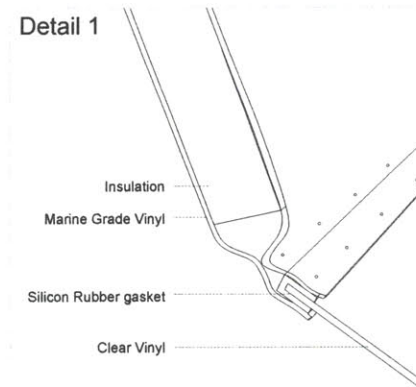
Scale = 1:30



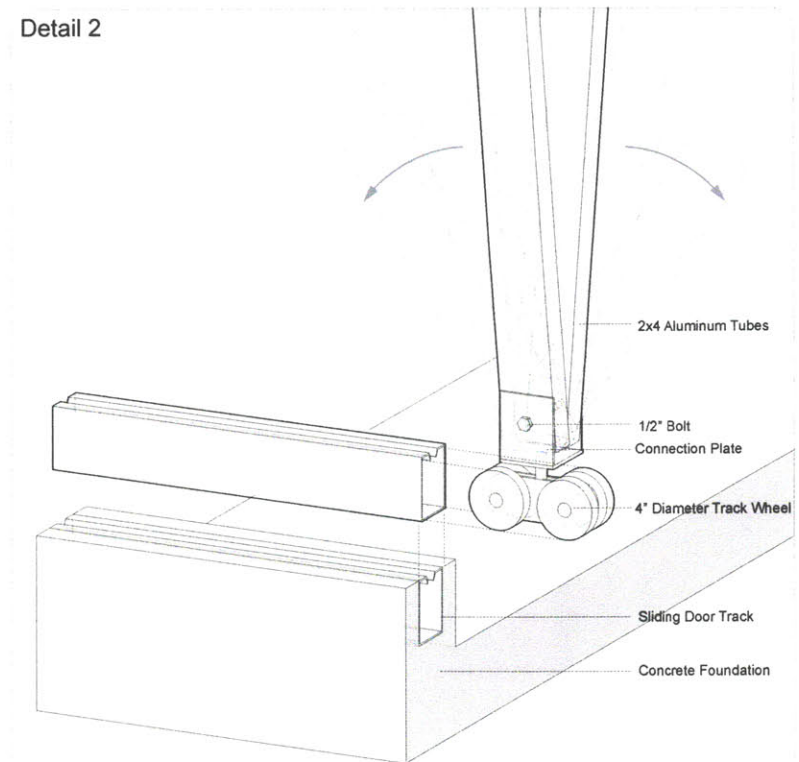
Section Scale = 1:35



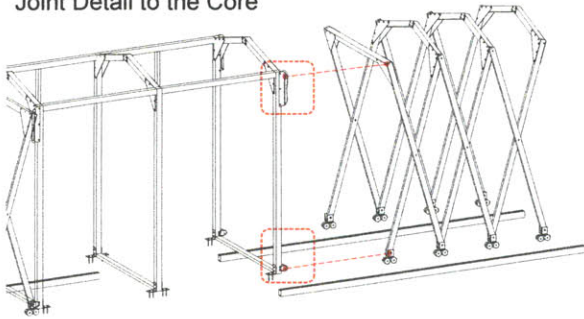
Detail 1



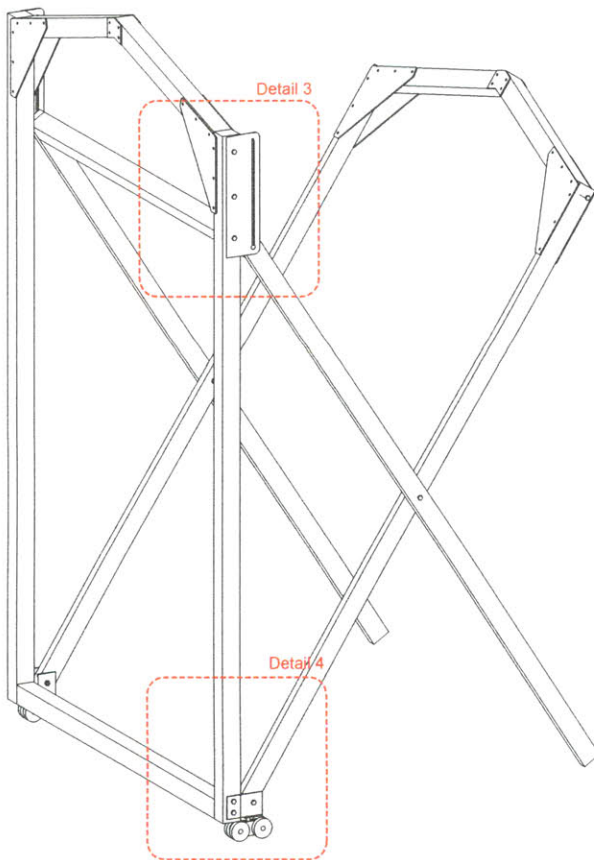
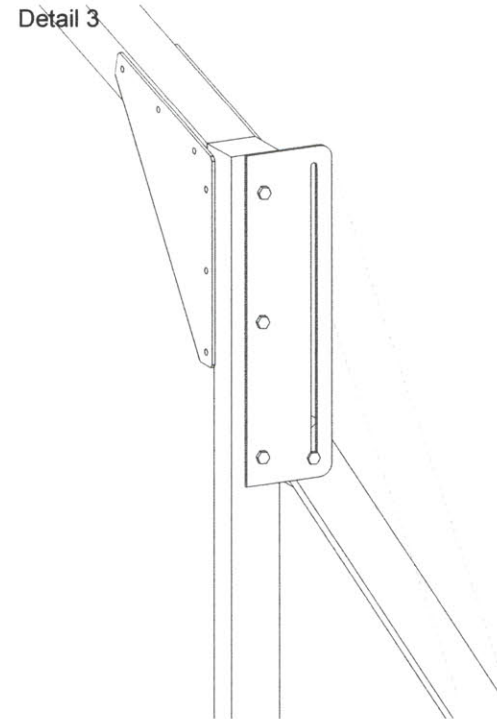
Detail 2



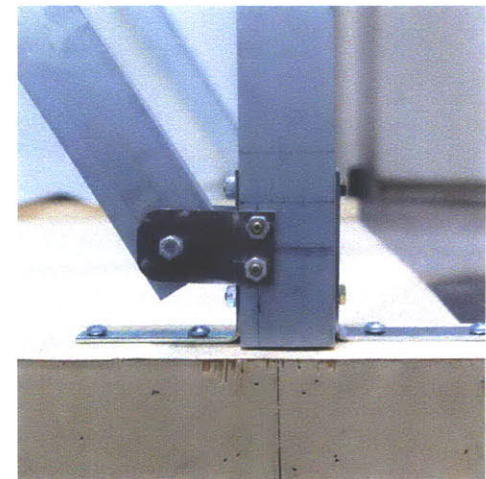
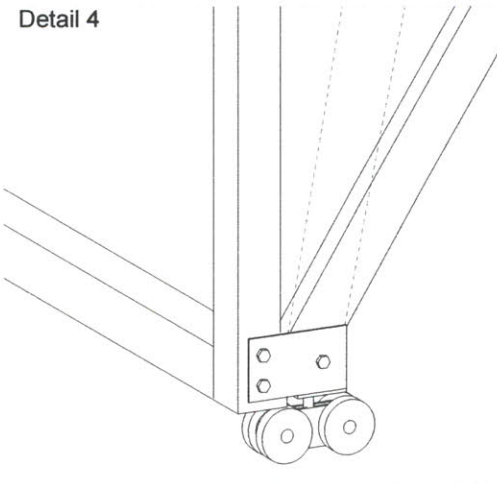
Joint Detail to the Core



Detail 3



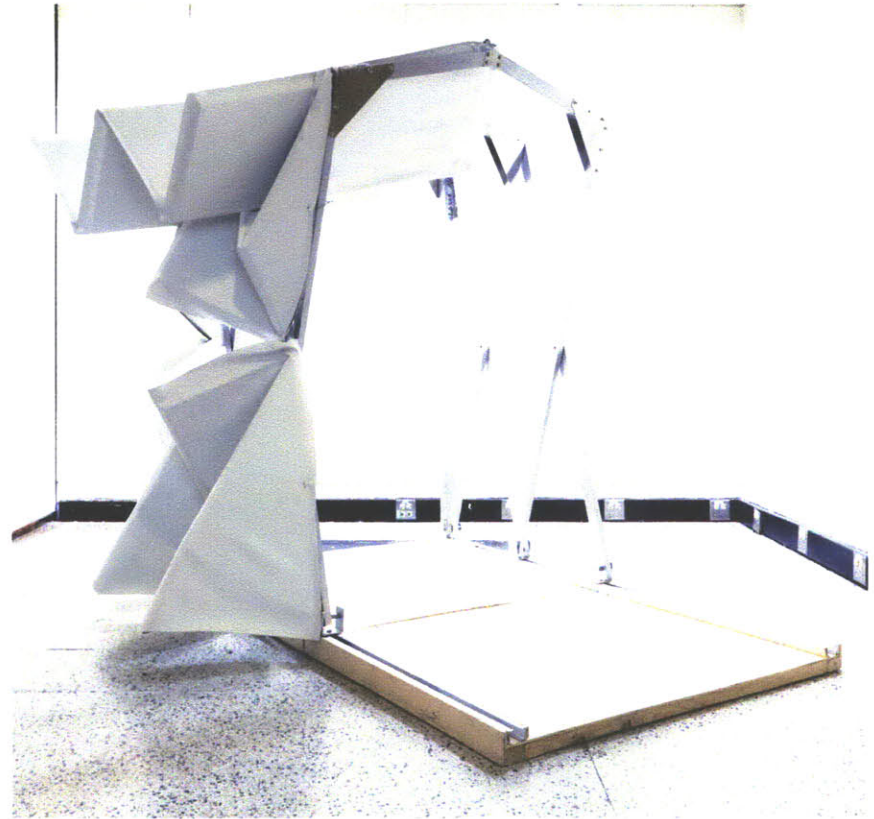
Detail 4

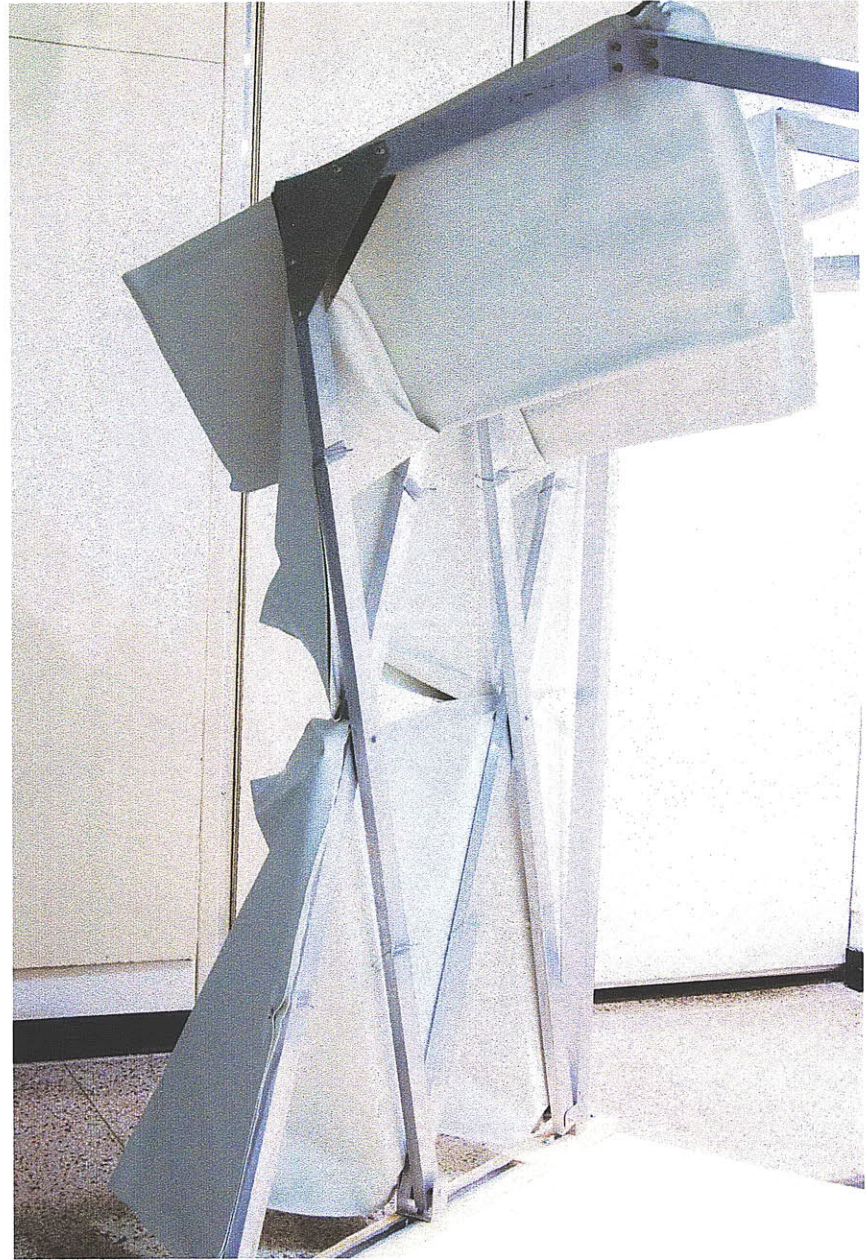
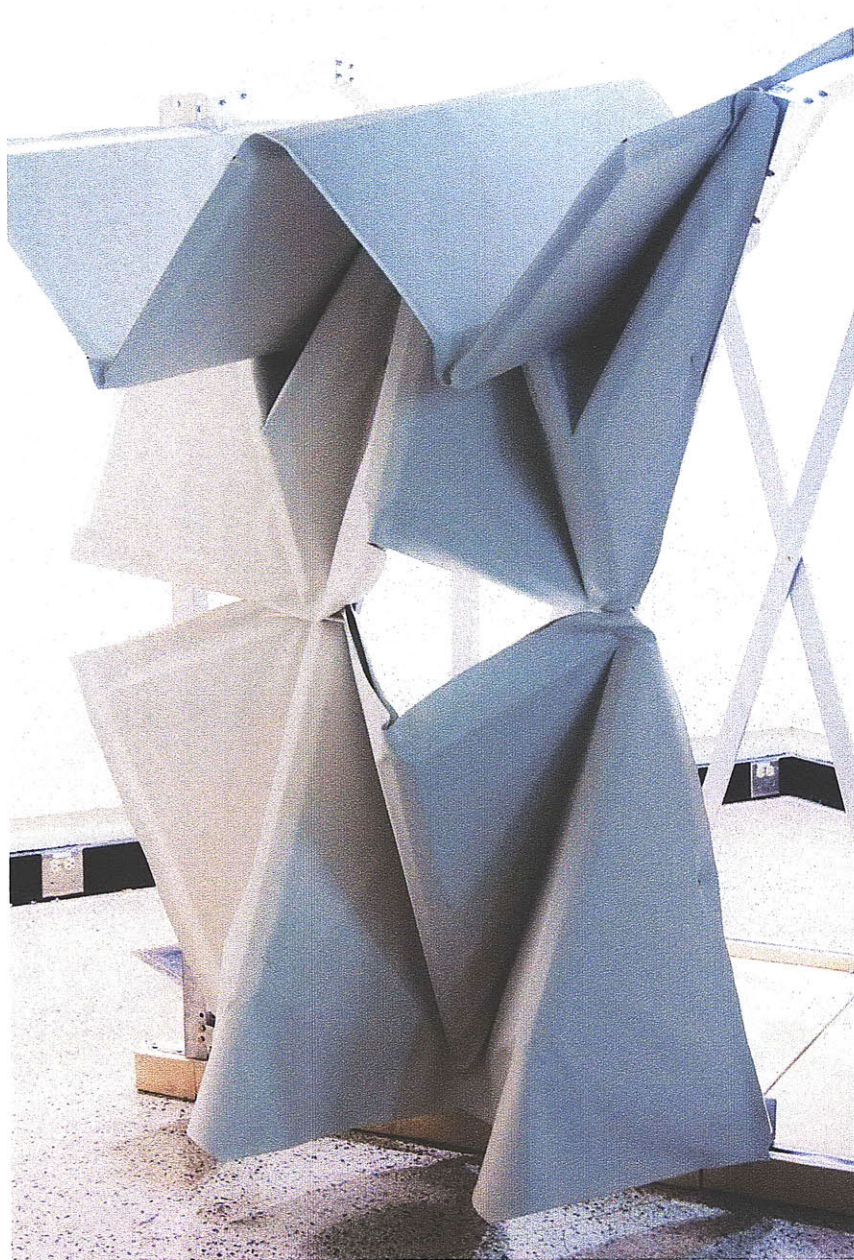


1:2 Mockup



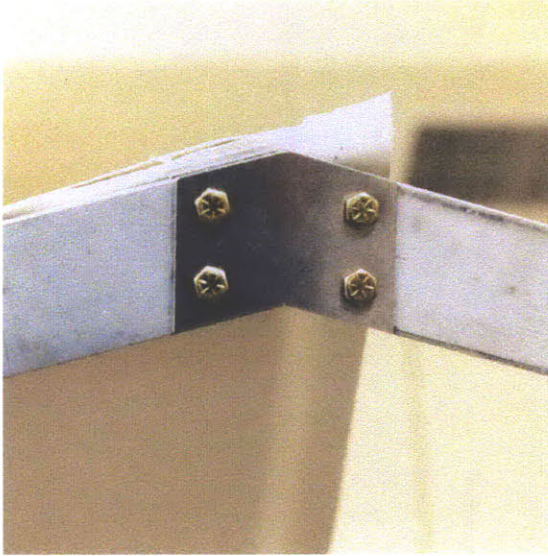
1:2 Mockup





1:2 Mockup Detail

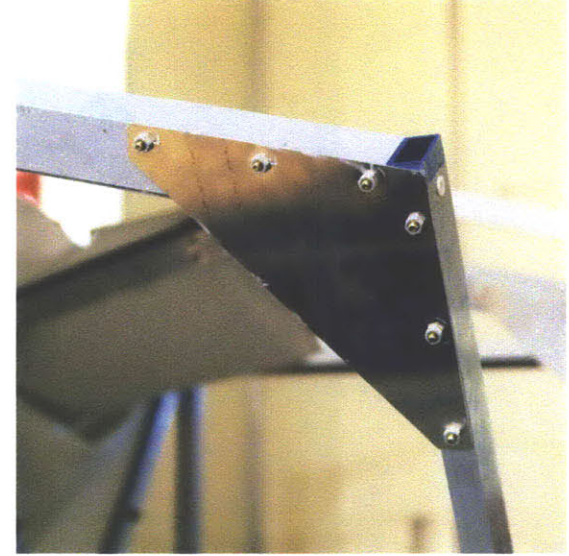
Pitched Roof Joint



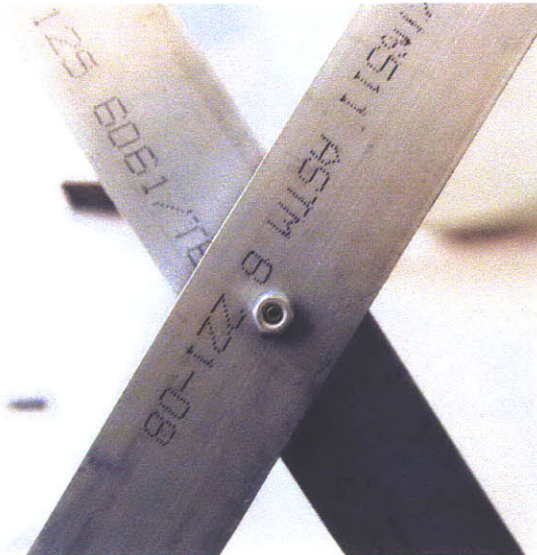
Roof and Column Joint



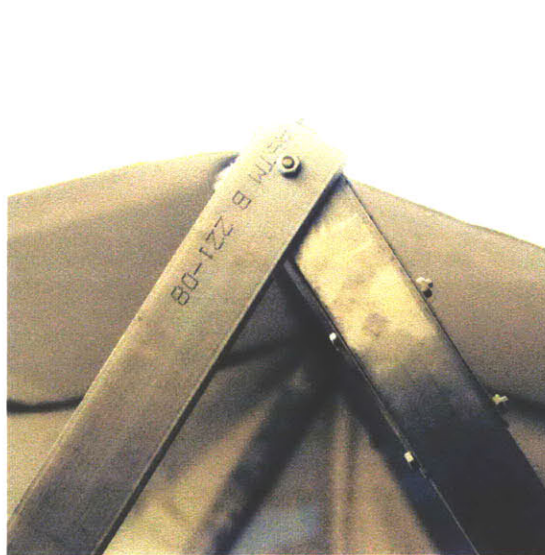
Roof and Column Joint



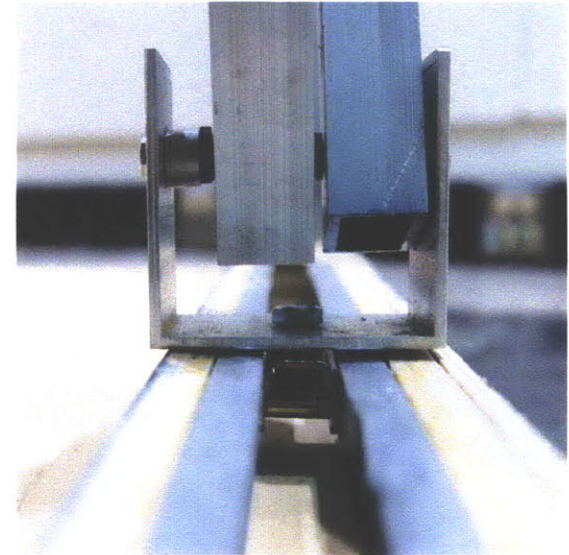
Bolt & Nut Swiveling Joint



Bolt & Nut Swiveling Joint

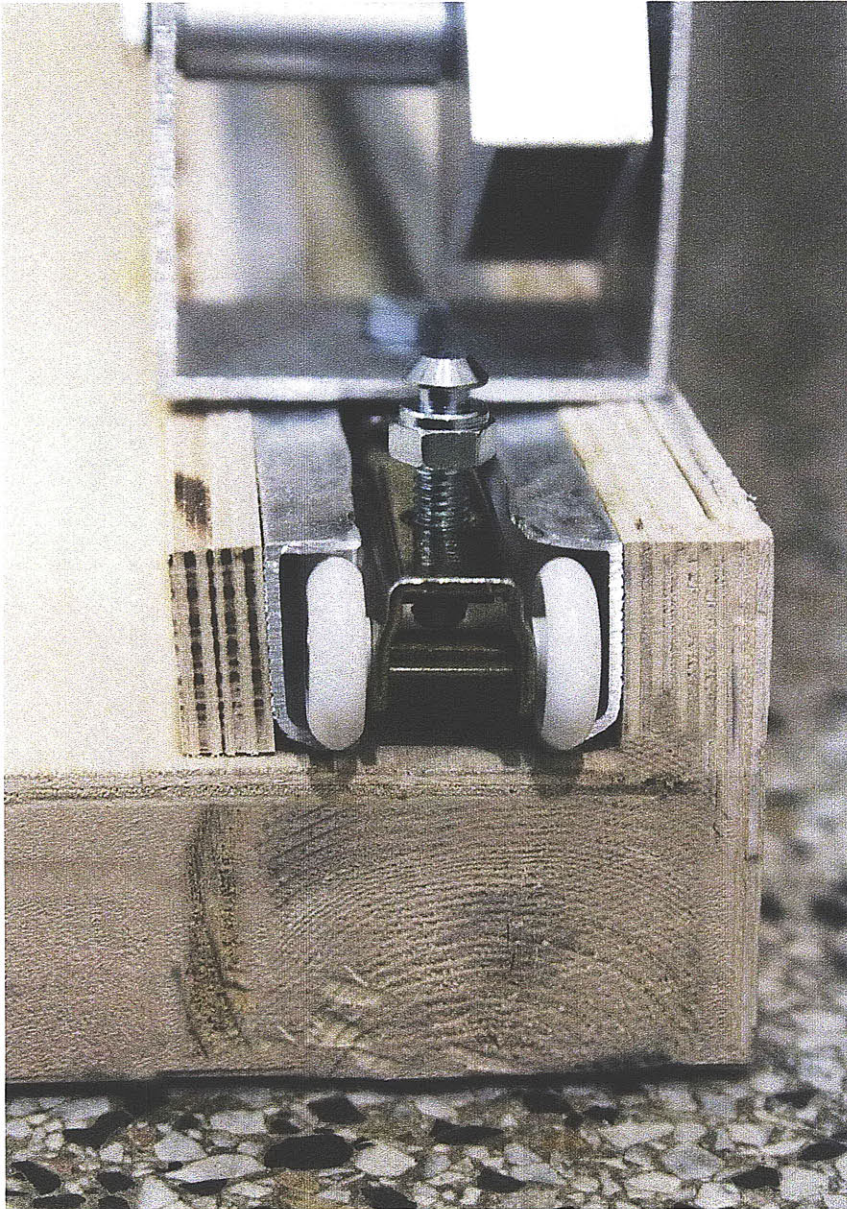


Swiveling Joint to Floor Track

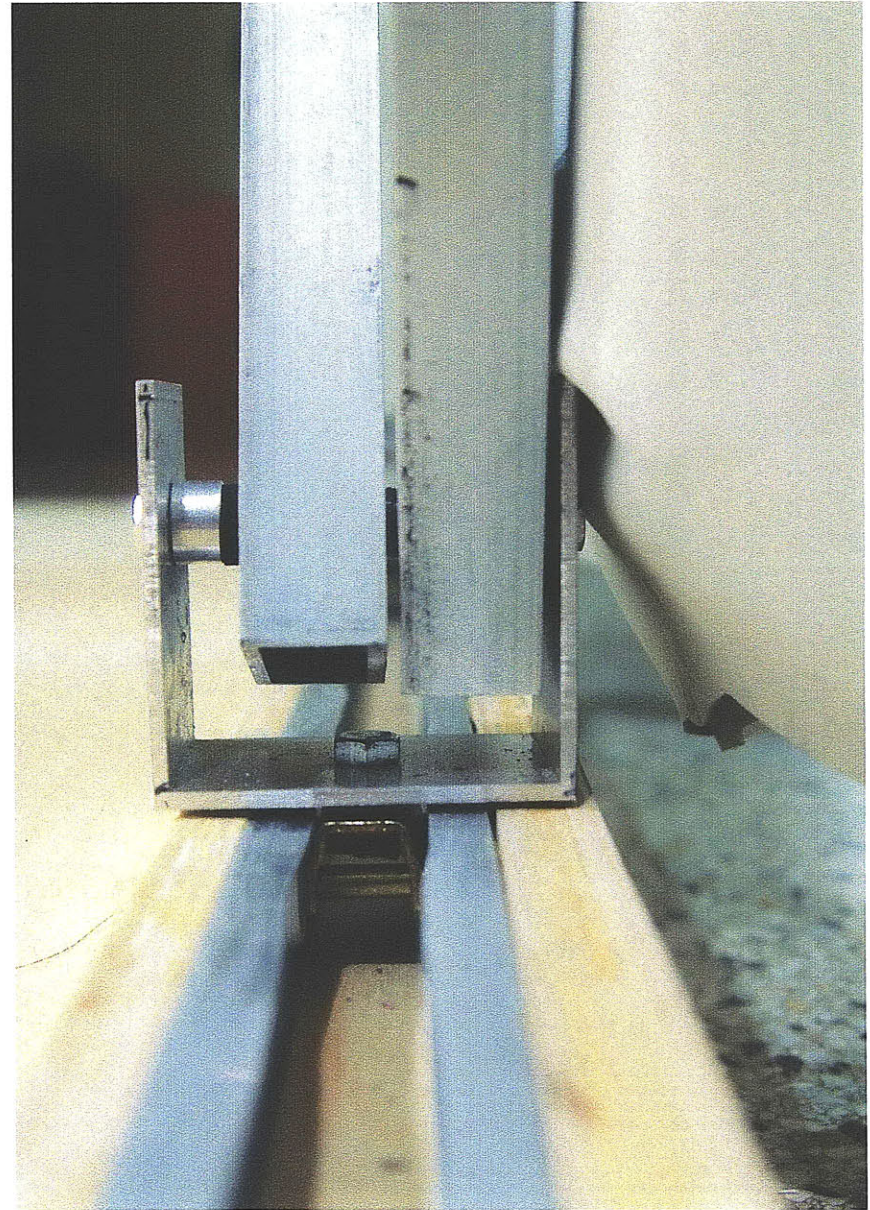


1:2 Mockup Detail

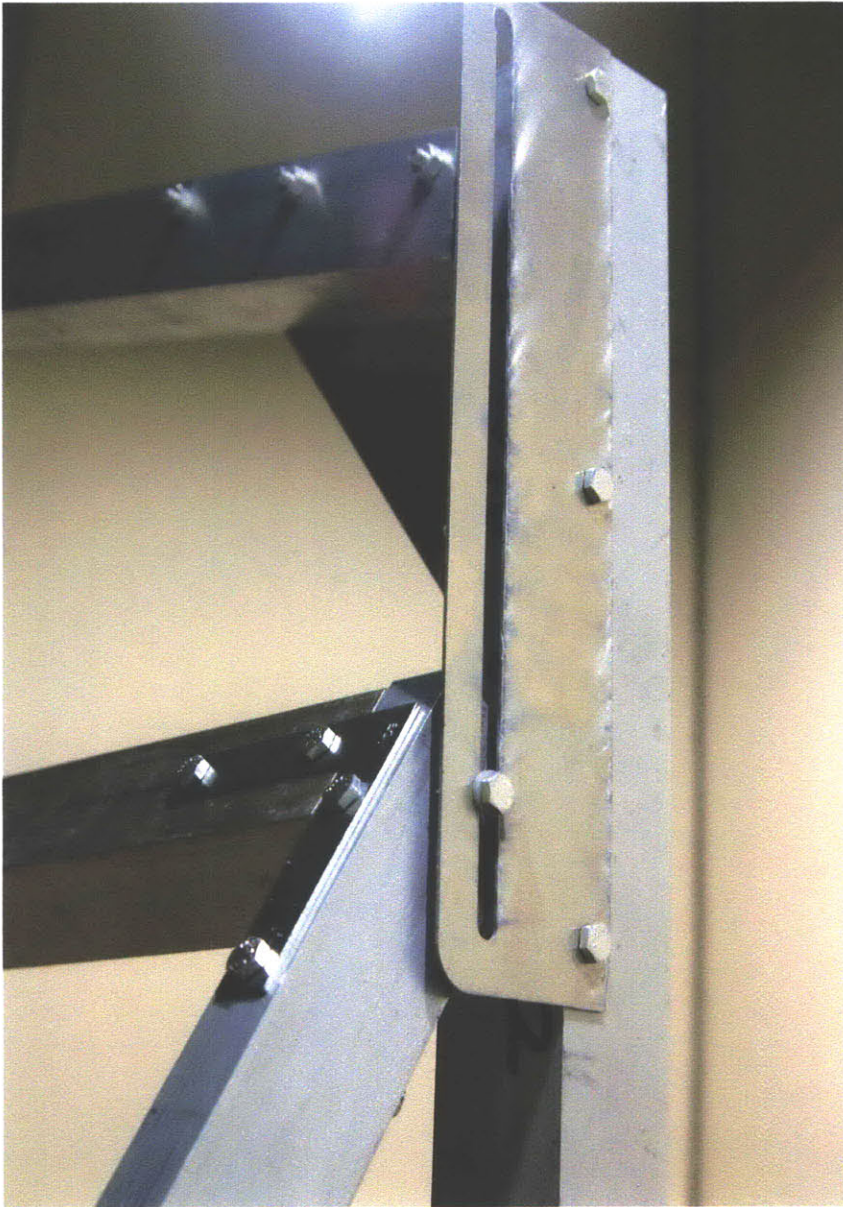
Roller and Track



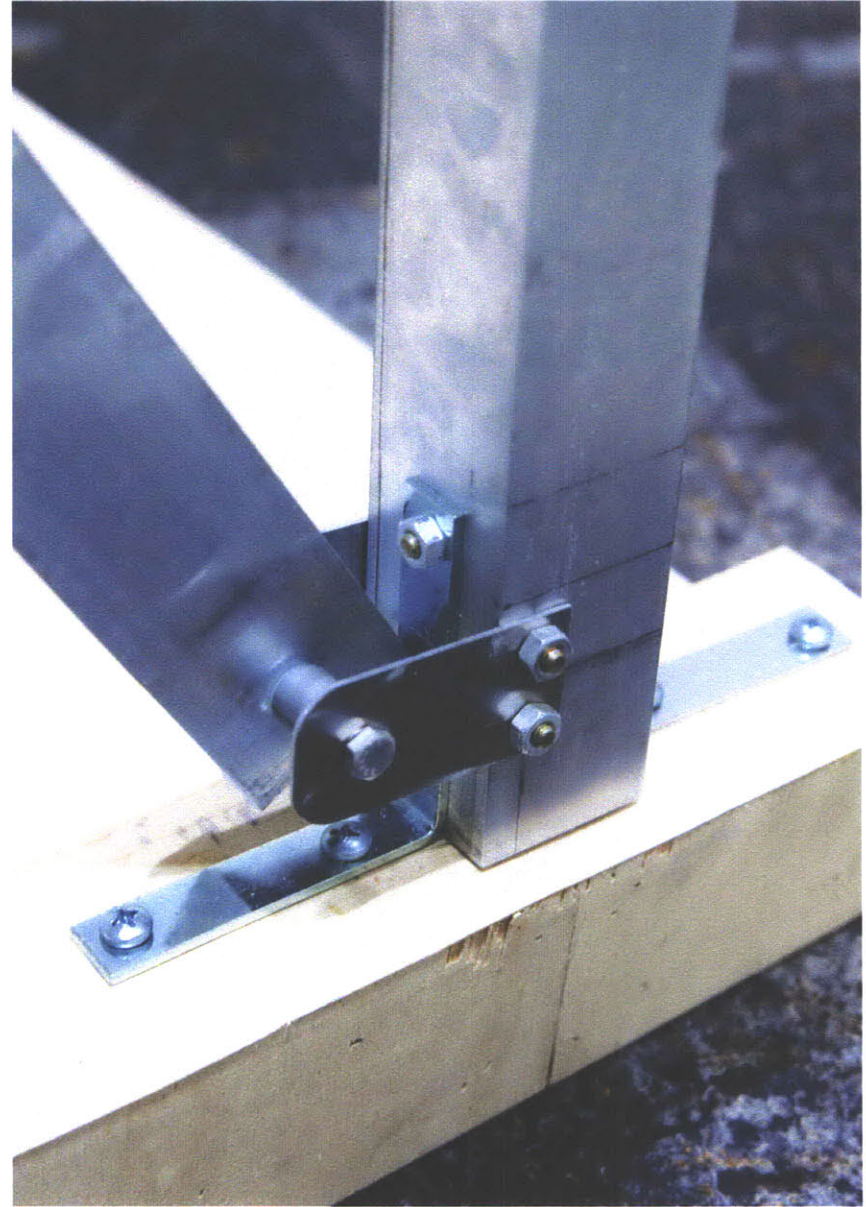
Swiveling Joint to Floor Track



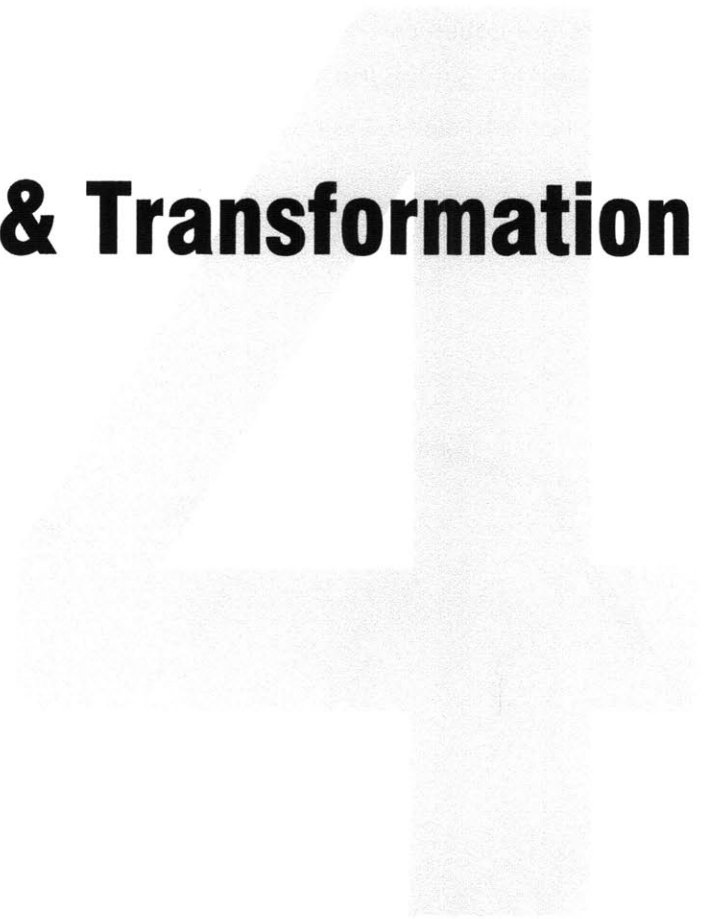
Joint to Column Core



Joint to the foundation

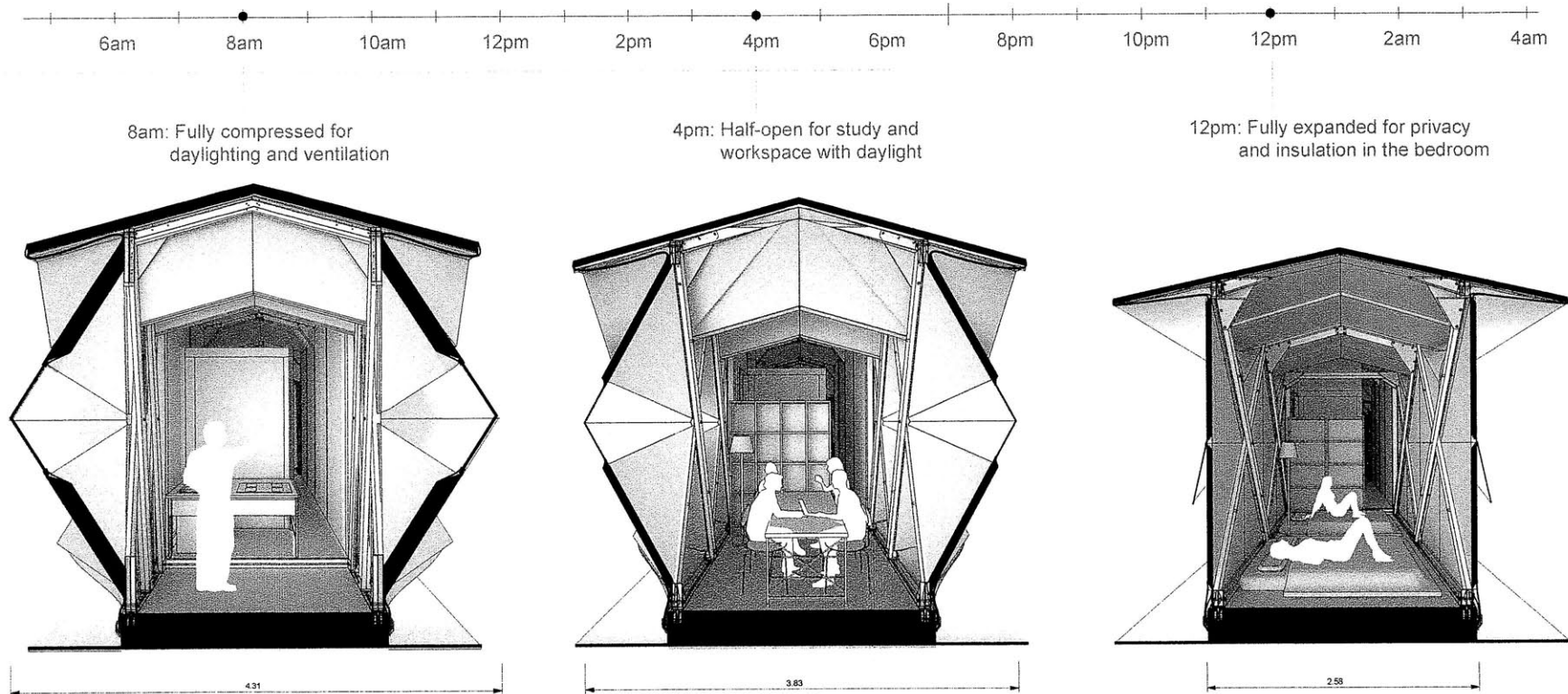


Program & Transformation



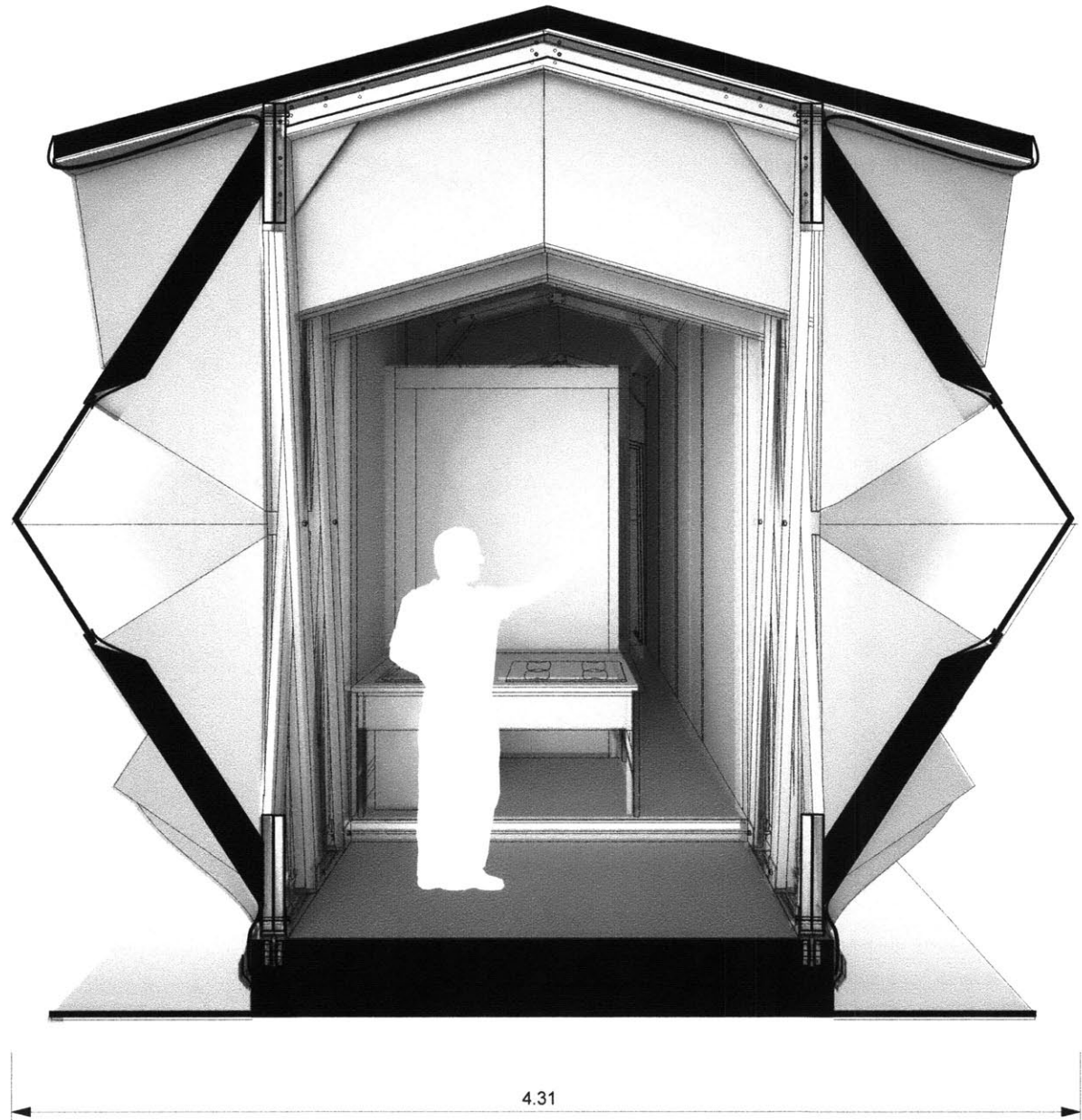
Sectional Perspective: Daily Transformation

The flexibility provides opportunities to operate the house in different climate conditions while providing multiple options for day lighting, insulation, and ventilation on a seasonal or daily basis. During the daytime when most family members are gone for work or school, the house can be compressed to save energy for daylighting and ventilation. On a sunny day, the structure can be compressed to open up the house for the family to enjoy the outdoors or host a garden party. During the night when the family have returned home to sleep, the house can be expanded for tight insulation.



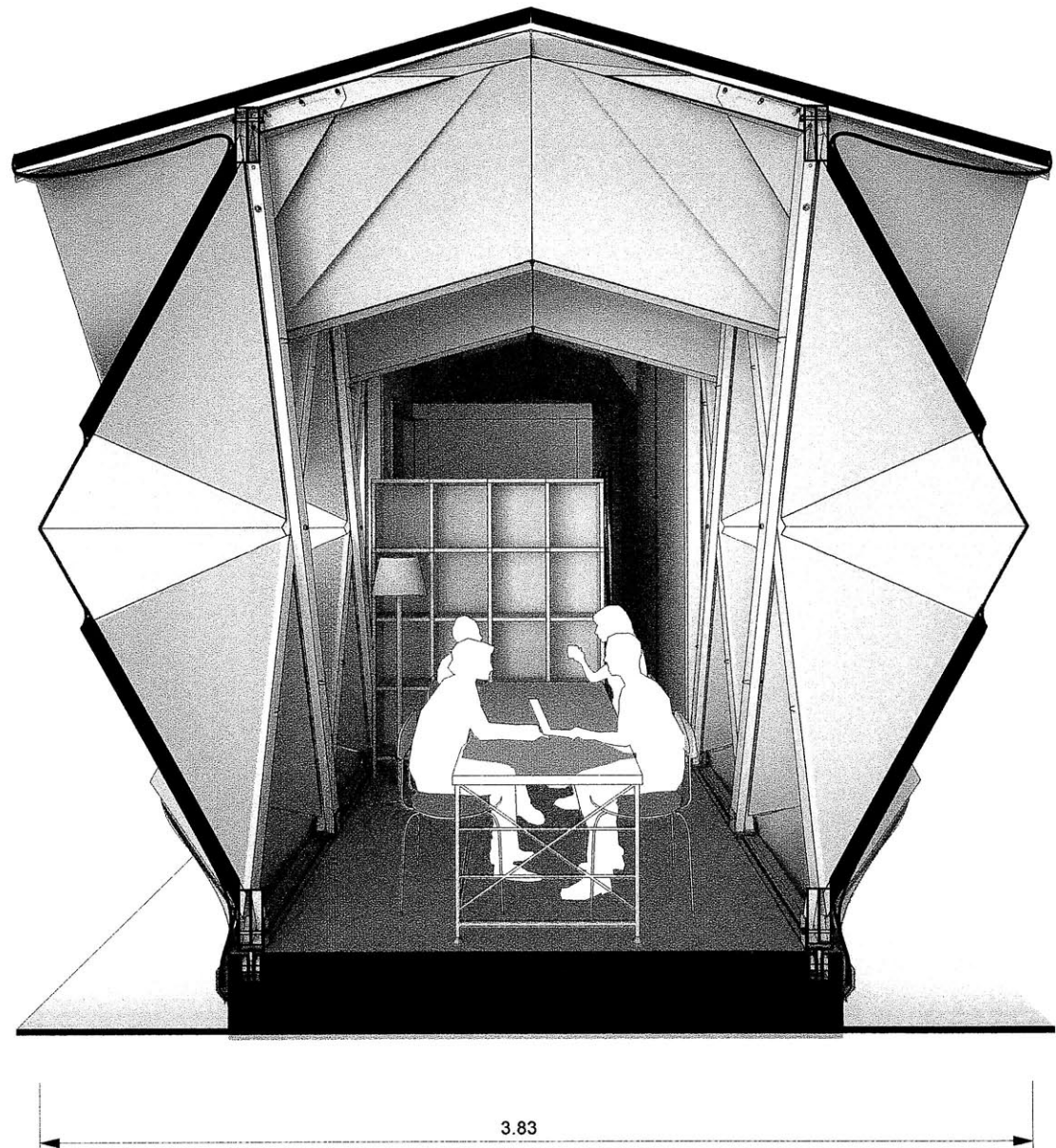
Sectional Perspective

8am: Fully compressed for
daylighting and ventilation



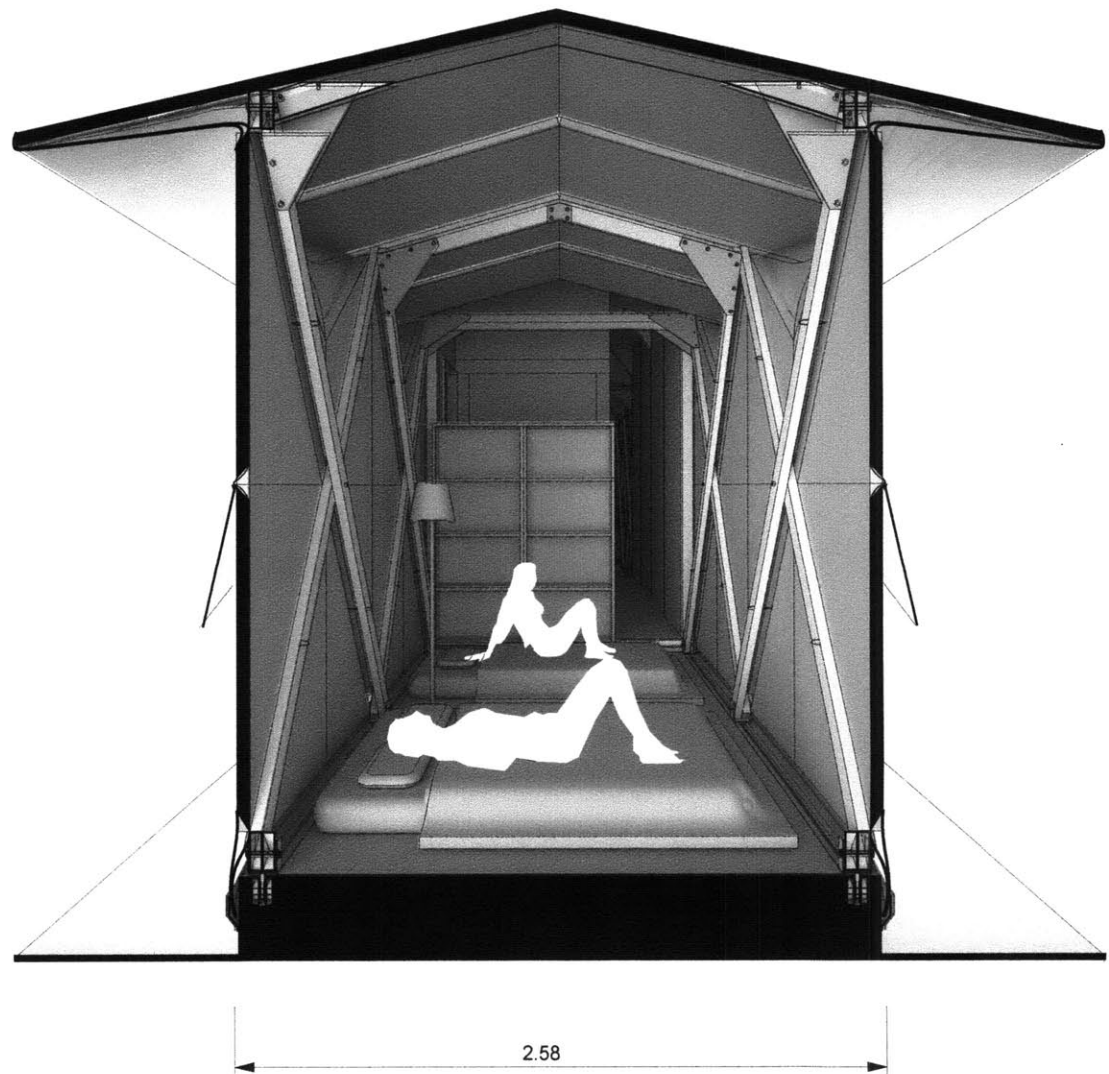
Sectional Perspective

4pm: Half-open for study and
workspace with daylight

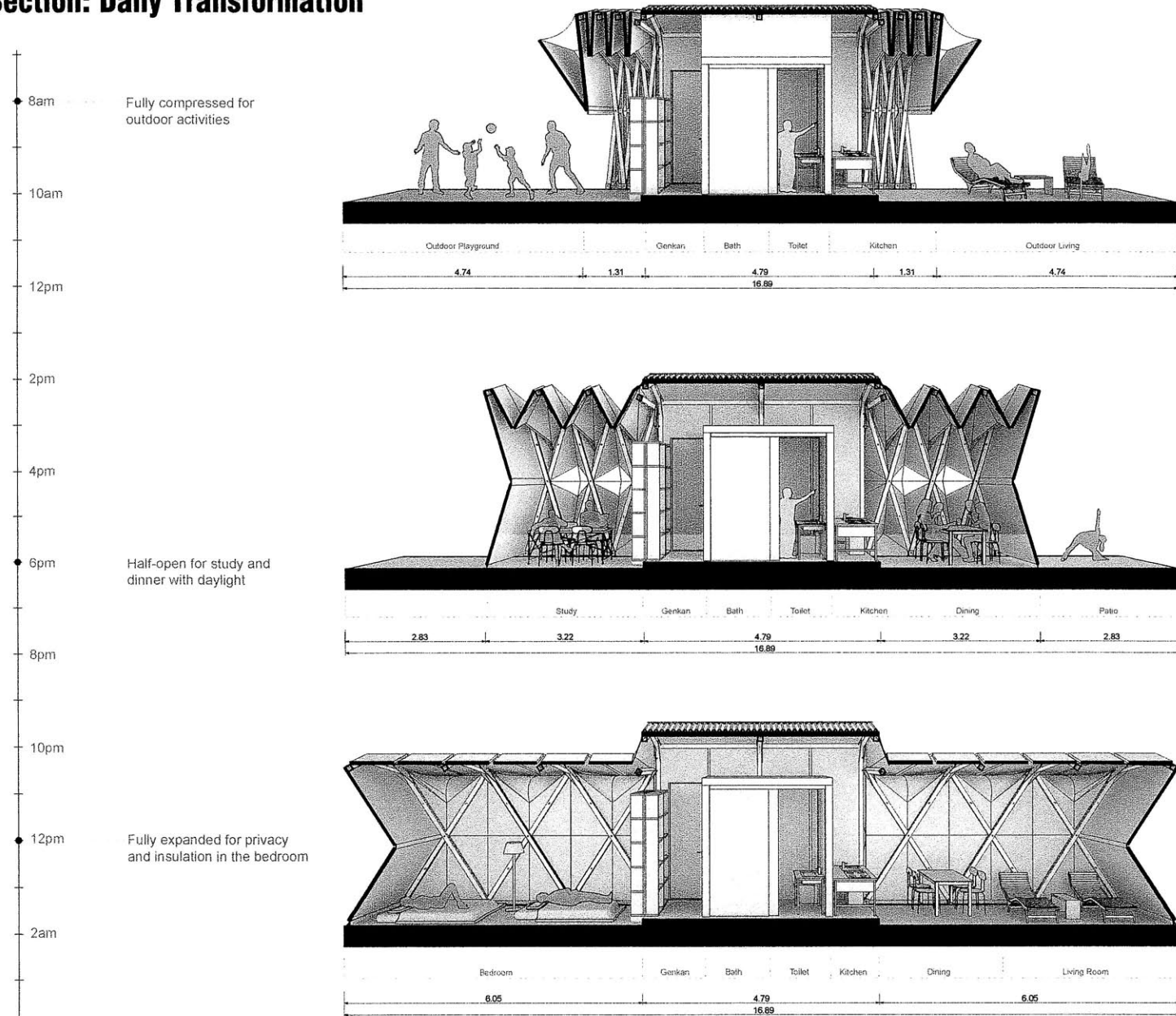


Sectional Perspective

12pm: Fully expanded for privacy
and insulation in the bedroom

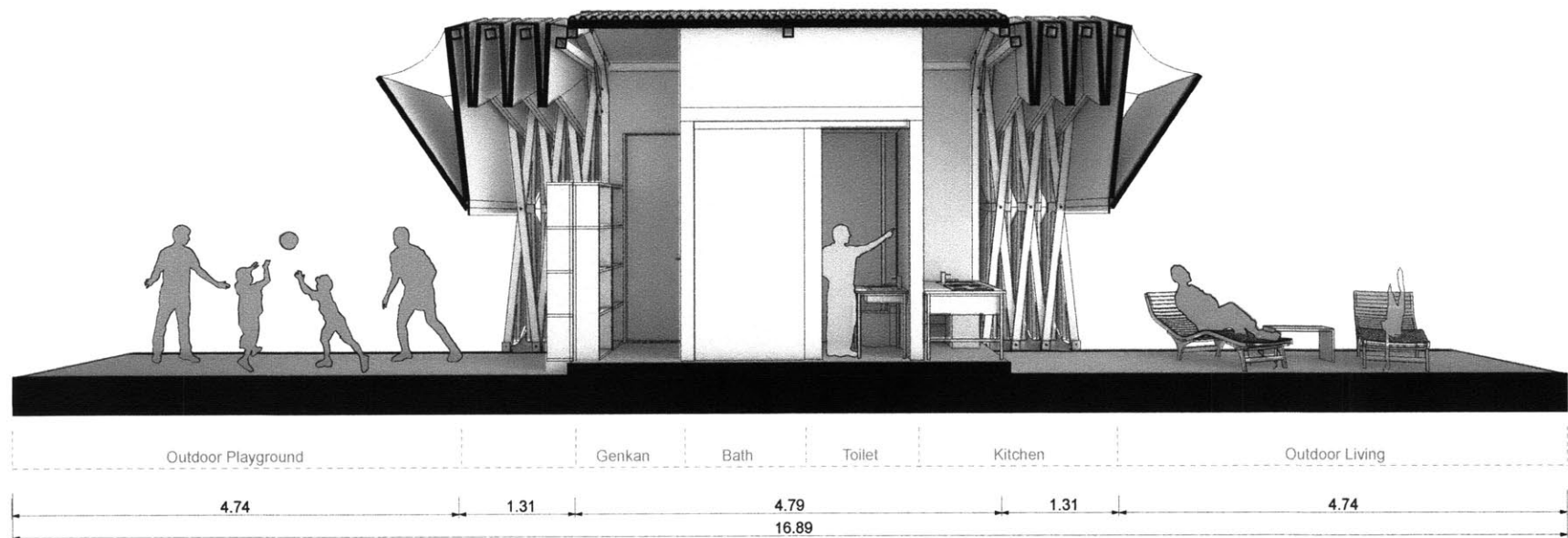


Section: Daily Transformation



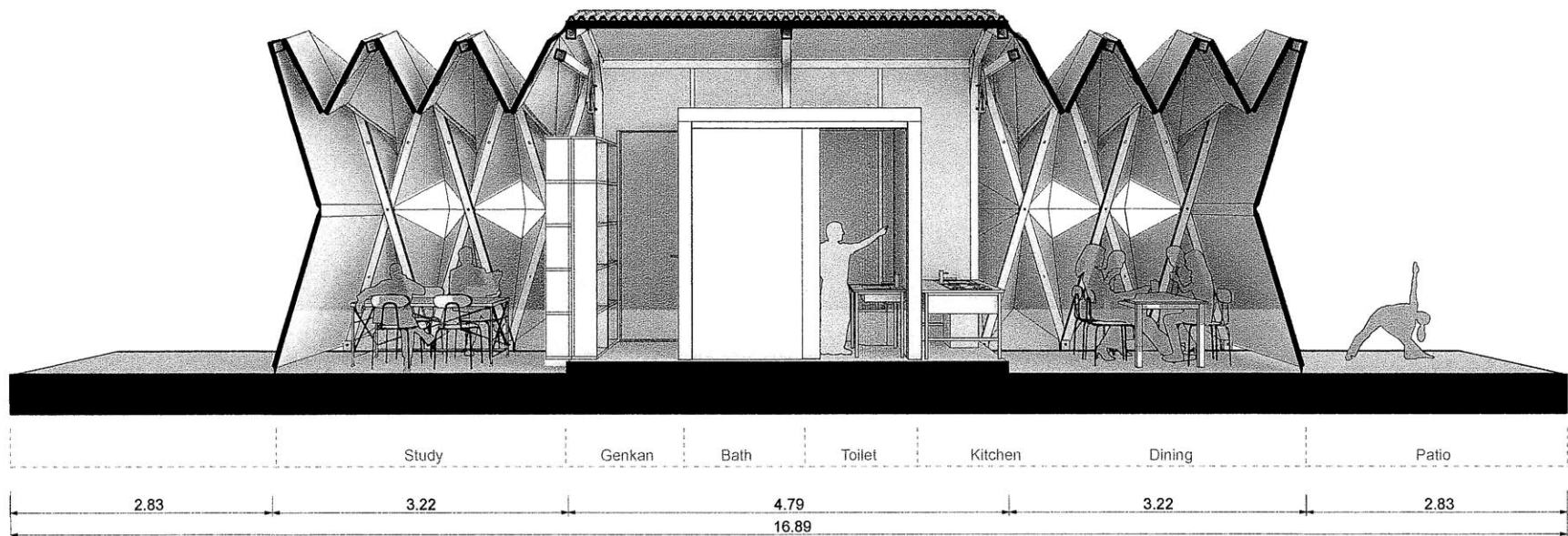
Section-Daily Transformation

8am: Fully compressed for outdoor activities



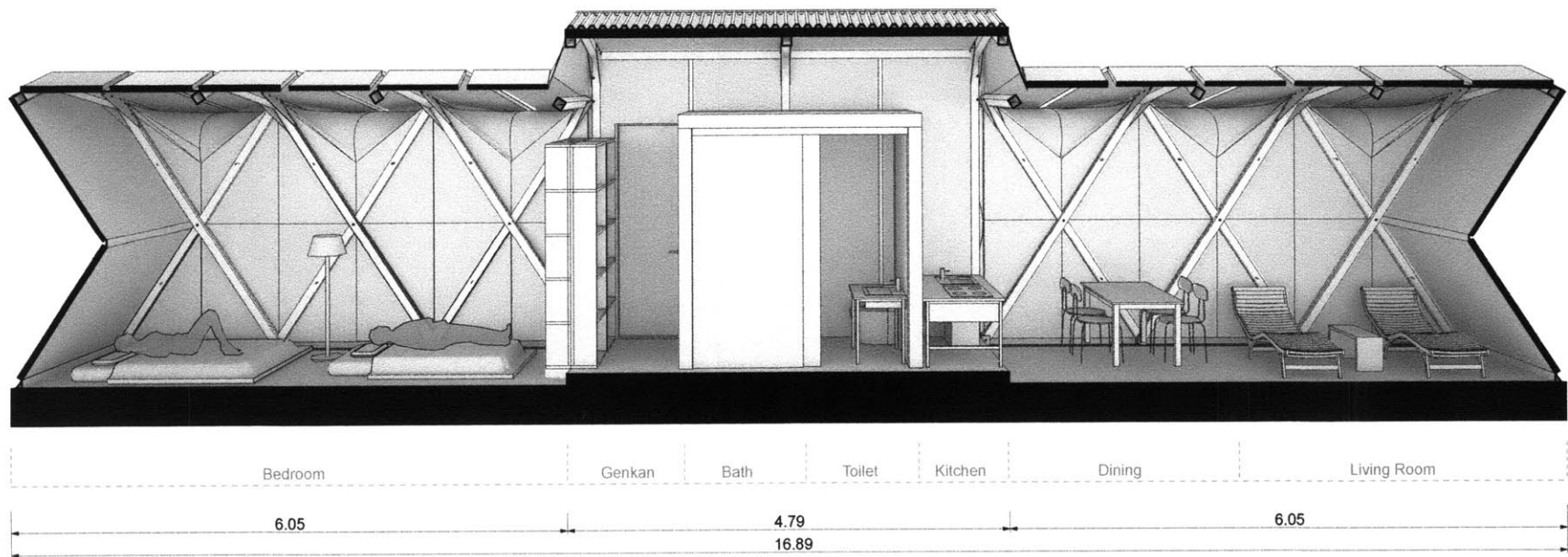
Section-Daily Transformation

6pm: Half-open for study and dinner with daylight

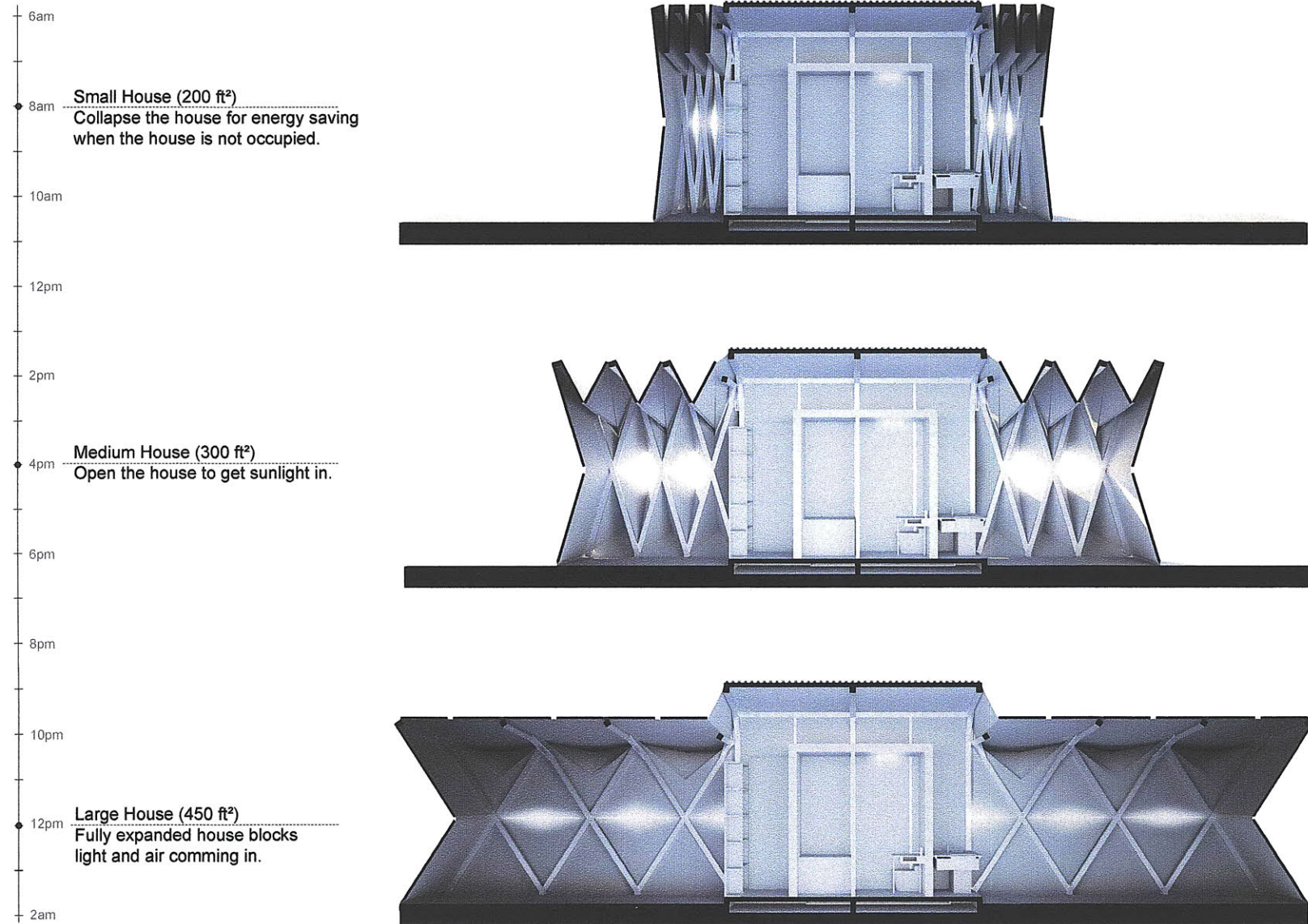


Section-Daily Transformation

12pm: Fully expanded for privacy and insulation in the bedroom



Daylighting study



Climate Control and Energy Saving

Large House

Area: 450 ft² (42m²)

Wall area: 1200 ft²

Thermal resistance of the wall: R10 for 2"extruded polystyrene insulation

Heat gain rate for summer: 34272 BTU/day (10.044 kwh/day)

Heat loss rate for winter: 119808 BTU/day

Cooling cost for summer: 10.044 kwh/day x \$0.27 = **\$2.7 / day**

Heating cost for winter: 119808 BTU x 17\$ / 70%(efficiency) = **\$2.9 / day**

Japan Climate condition

Japan Average Temperature: 15.1°C (59 °F)

August average max/high temperature: 31°C (88 °F)

January average min/low temperature: -1°C (30 °F)

Japan Electricity cost: \$0.27 per 1kwh (\$0.15 in US)

Japan Natural gas cost: \$17 per million BTU (\$12 in US)

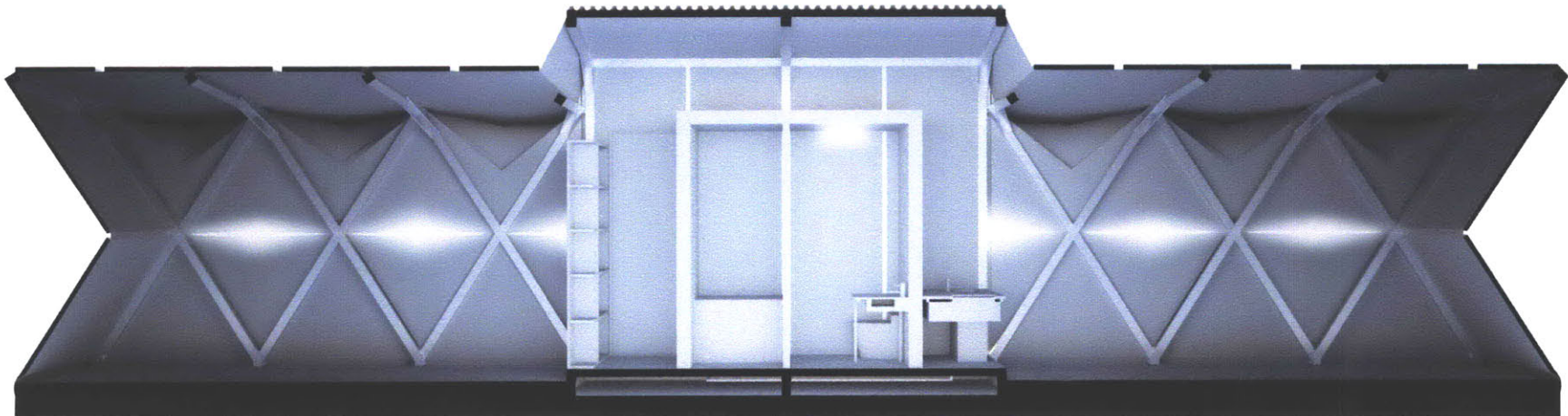
Thermal Comfort

Operative temperature by Ashrae for summer:

23.5~25.5 °C (74.3~77.9 °F)

Operative temperature by Ashrae for winter:

21.0~23.0 °C (69.8~73.4 °F)



Climate Control and Energy Saving

Medium House

Area: 300 ft² (28m²)

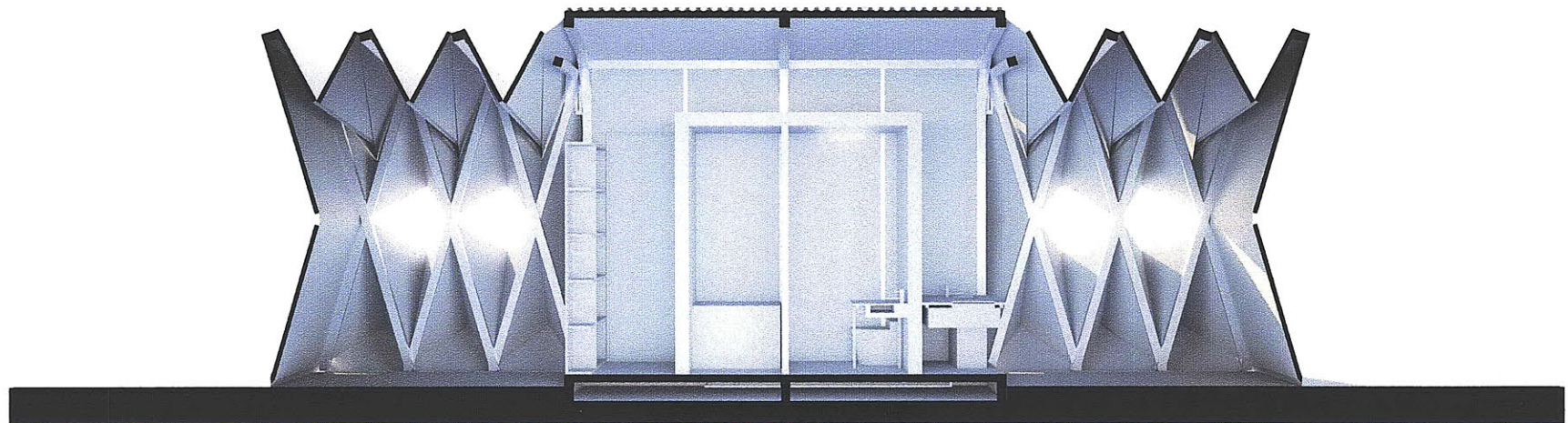
Thermal resistance of the wall: R15

Heat gain rate for summer: 34272 BTU/day (10.044 kwh/day)

Heat loss rate for winter: 119808 BTU/day

Cooling cost for summer: 10.044 kwh/day x \$0.27 = **\$1.8 / day**

Heating cost for winter: 119808 BTU x 17\$ / 70%(efficiency) = **\$1.9 / day**



Climate Control and Energy Saving

Small House

Area: 200 ft² (19m²)

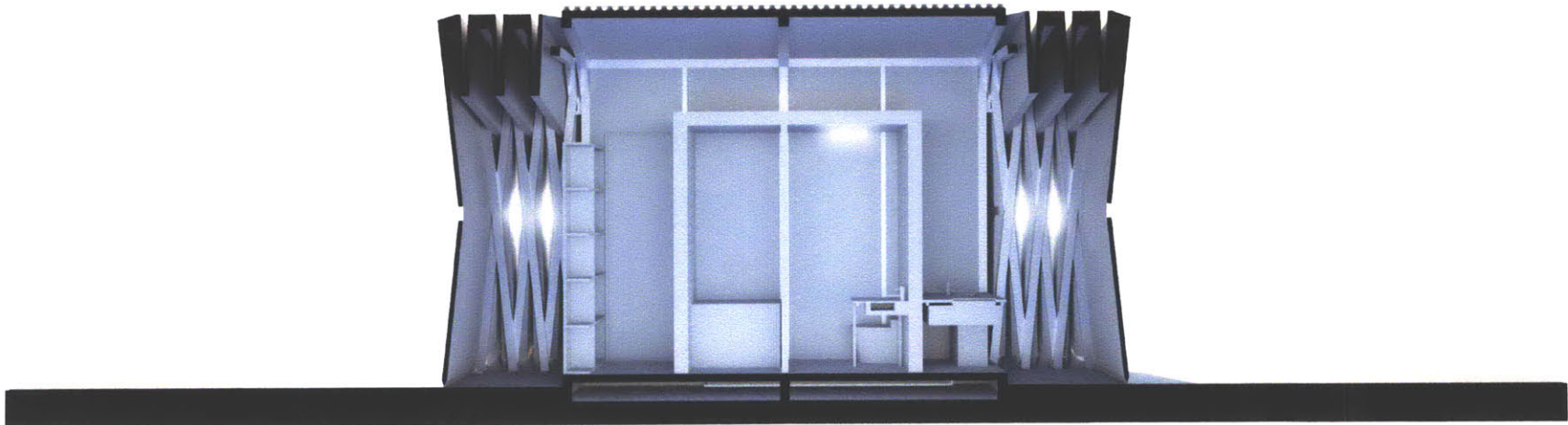
Thermal resistance of the wall: R22.5

Heat gain rate for summer: 34272 BTU/day (10.044 kwh/day)

Heat loss rate for winter: 119808 BTU/day

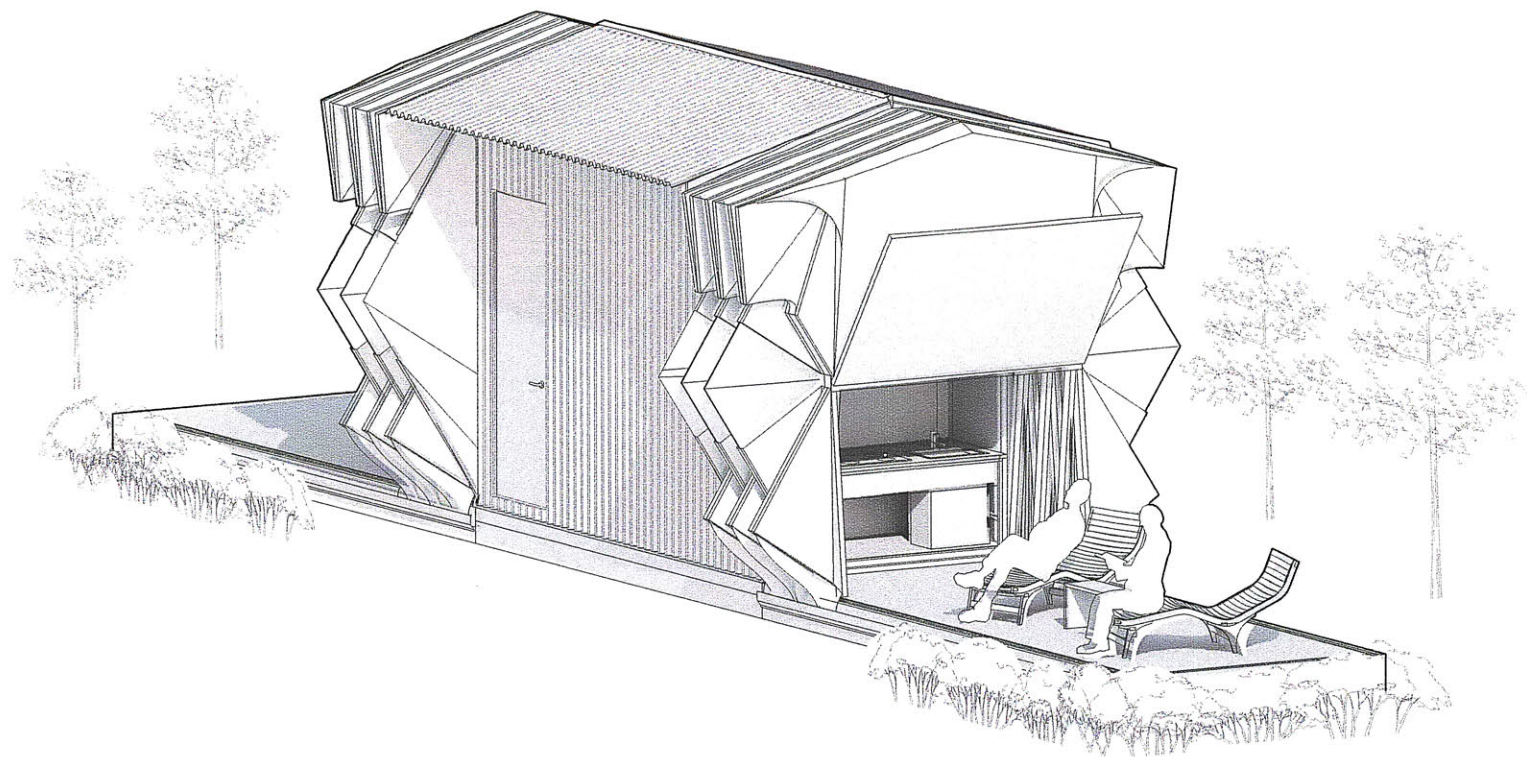
Cooling cost for summer: 10.044 kwh/day x \$0.27 = **\$1.2 / day**

Heating cost for winter: 119808 BTU x 17\$ / 70%(efficiency) = **\$1.9 / day**

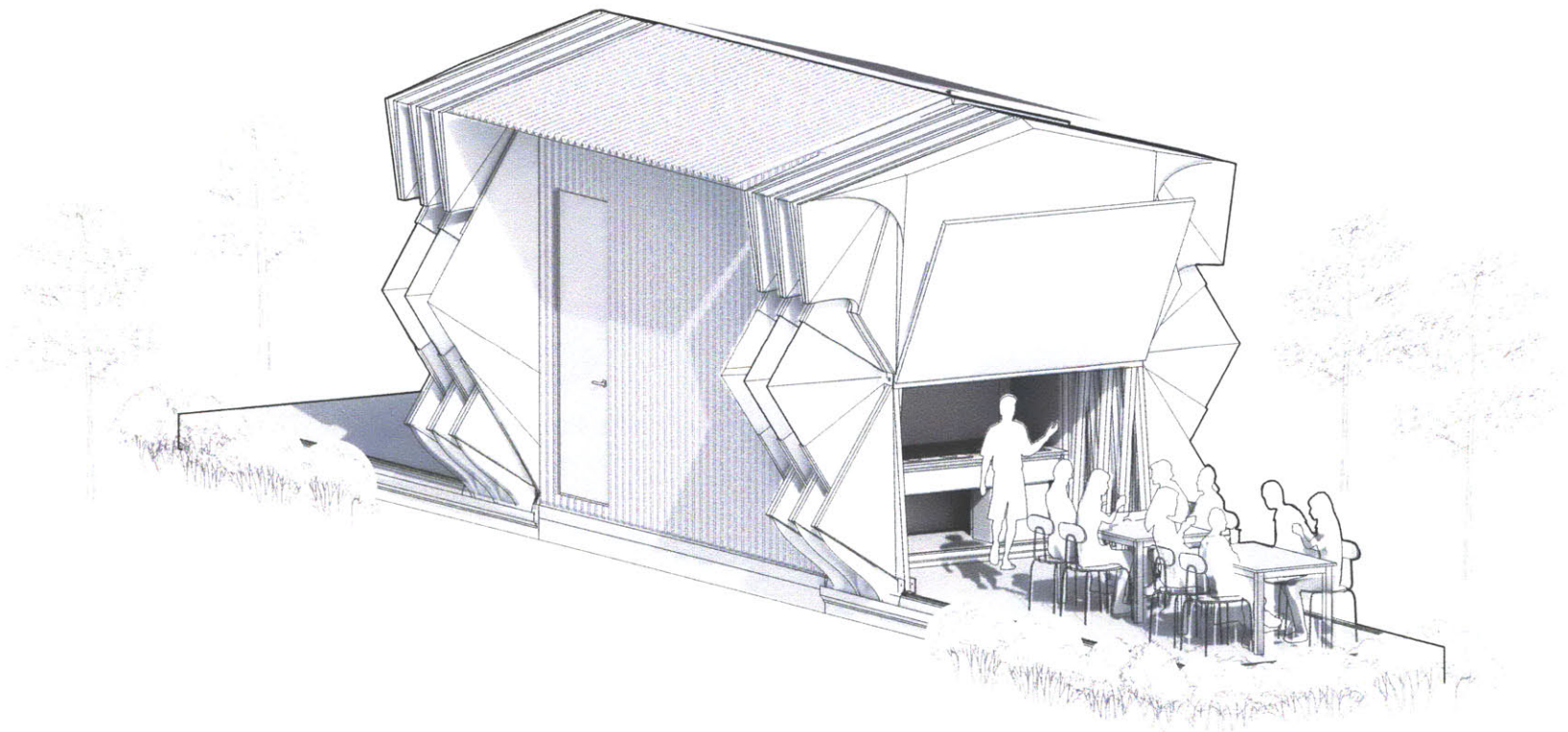


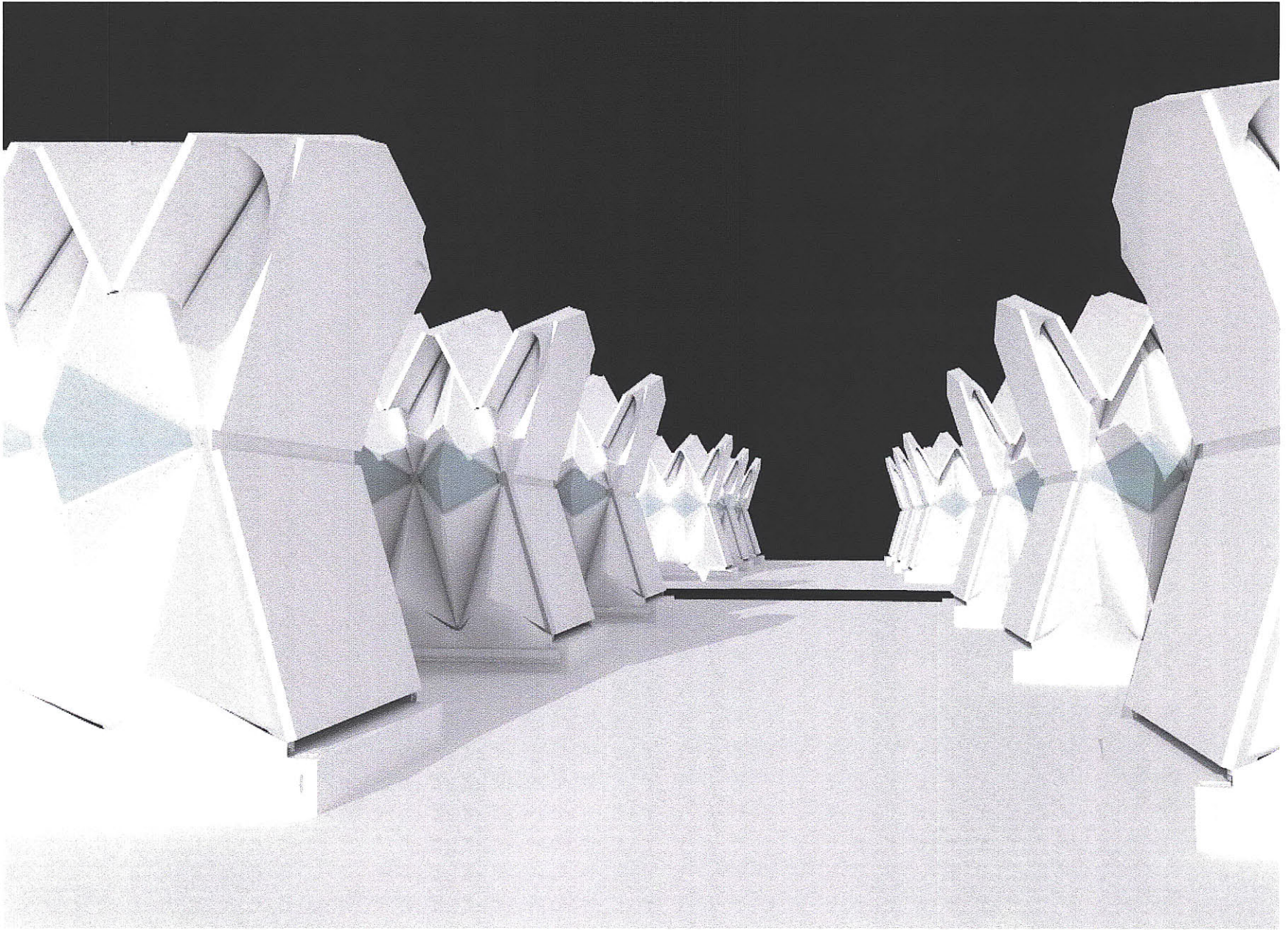
Axonomic

Foldable House for Outdoor Living



Foldable House to Host a Garden Party





Bibliography

Davis, Ian. Shelter After Disaster. Oxford: Oxford Polytechnic Press, 1978

Corsellis, Tom, and Antonella Vitale. Transitional Settlement: Displaced Populations. Oxford: Oxfam GB, 2005.

Transitional Shelter Guidelines. Shelter Centre, 2011

Johnson Cassidy, "Planning for temporary housing," Rebuilding after disasters: from emergency to sustainability, London, New York: Spon Press, 2010

Kronenburg, Robert. Houses in Motion: The Genesis, History, and Development of the Portable Building. London: Academy Editions, 1995.

Schwartz-Clauss, Mathias. Living in Motion: Design and Architecture for Flexible Dwelling ; Weil am Rhein: Vitra Design Museum, 2002.

Melis, Liesbeth. Parasite Paradise: A Manifesto for Temporary Architecture and Flexible Urbanism. Rotterdam: NAI Publishers/SKOR, 2003.

Davies, Colin. Key Houses of the Twentieth Century: Plans, Sections and Elevations. London: Laurence King, 2006

Casartelli, Tiziano. Villa Girasole: La Casa Rotante = the Revolving House. Mendrisio (CH: Mendrisio Academy Press, 2006